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Vol. 211 JUNE, 1931 No. 6

RECENT ADVANCES IN THE PRODUCTION AND MEASUREMENT OF HIGH VACUA.*

BY

SAUL DUSHMAN, Ph.D.,

Assistant Director, Research Laboratory,
General Electric Company.

INTRODUCTION.

The interest in high vacua began about eighteen years ago with the investigations on electron emission and the application of electronic devices in radio and other fields. About ten years ago the writer published a series of articles on this subject in the *General Electric Review*, which afterwards was incorporated in a book. In this and other works published at about the same time, or a little later,[1] the technique of the production of high vacua and the methods

* Presented at the Stated Meeting held Wednesday, December 17, 1930.

[1] References on High Vacuum Technique:

(1) L. Dunoyer, "Vacuum Practice," D. Van Nostrand and Company, New York, 1926.

(2) F. H. Newman, "The Production and Measurement of Low Pressures," D. Van Nostrand Company, New York, 1925.

(3) G. W. C. Kaye, "High Vacua," Longmans, Green and Company, 1927.

(4) S. Dushman, "High Vacuum," *General Electric Review*, 1922; also translated by R. G. Berthold and E. Reimann, Julius Springer, Berlin, 1926.

(5) A Goetz, "Physik und Technik des Hochvakuums," Friedr. Vieweg und Sohn, Akt. Ges., Braunschweig, 1926.

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of measurement of extremely low pressures have been discussed very fully. Furthermore, the knowledge on this subject has become wide-spread both among those interested in purely scientific investigations and those engaged in the commercial manufacture of various vacuum devices.

In view of these circumstances it has seemed best to discuss in the present paper, firstly, the advances which have been made in the field during the past few years, and, secondly, the results of a number of investigations which are of fundamental importance in this connection.

The lines along which greatest progress has been made during the past decade may be described under the following three headings:

(1) Utilization of vapor pumps of much higher speeds.
(2) Use of "getters" or "clean-up" methods to improve vacuum in devices after preliminary exhaust.
(3) Increasing attention to vacuum treatment of metals and metal parts that enter into the production of vacuum devices.

In presenting the following remarks on these topics, a great deal of the material has been obtained from laboratory reports and personal discussions with different members of the Research Laboratory. While the particular individuals who have contributed to various developments are mentioned in each instance, the writer wishes to take this opportunity of expressing his indebtedness to all these members of the organization, and especially to Mrs. M. R. Andrews and Mr. J. H. Payne, for permission to use their information in this paper.

GENERAL CONSIDERATIONS REGARDING VACUUM PUMPS.

Before discussing the development of the high speed pumps, it is essential to observe that the main requirements of any exhaust system are as follows:

(1) Production of extremely low pressure.

(2) High speed which is independent of the fore-pump pressure and also (in case of vapor pumps) of temperature of boiler, within as wide limits as possible.

DEGREE OF VACUUM OBTAINED.

In present vacuum practice, it may be regarded as axiomatic that the pump must be capable of exhausting to a pressure of less than 10^{-5} mm. of mercury, and preferably as low as 10^{-6} mm. While the scientific unit of pressure is designated as the barye and is defined as 1 dyne per cm.[2], the more convenient technical unit is taken as 1 micron = 10^{-3} mm. of mercury.[2] Hence it may be stated as a fundamental requirement of a high vacuum system that it shall be capable of reducing the pressure to about 10^{-3} microns of mercury. Practically all types of mercury vapor pumps satisfy this condition. In the case of single stage pumps, such as described subsequently, this necessitates the use of a moderately low fore-pump pressure (10^{-3} mm. approximately), while with two or three stage pumps, the backing pressure may be as high as 10 mm. of mercury.

It is interesting to note that even at this comparatively "high vacuum" of 10^{-3} microns, the number of molecules at 0° C. is 3.56×10^{10} per cm.[3], which indicates how far removed this condition is from that of a "perfect" vacuum. On the other hand, in terms of atmospheric pressure, it represents a reduction of almost 10^{-9}.

SPEED OF EXHAUST.

The *speed* of an exhaust system, S, is defined by the relation

$$-\frac{dp}{dt} = \frac{S}{V}(p - p_0), \tag{1}$$

where p is the pressure at any instant, V denotes the volume of system exhausted, and p_0, the lower limit of pressure attainable. From this equation follows the relation

$$S = \frac{V}{(t_2 - t_1)} \log_e \left(\frac{p_1 - p_0}{p_2 - p_0} \right) \tag{2a}$$

or

$$p_2/p_1 = \epsilon^{-S(t_2 - t_1)/V}, \tag{2b}$$

[2] Since 750 mm. of mercury = 10^6 baryes to within 1 part in 10,000, we obtain the relation

1 barye = 0.75×10^{-3} mm.
1 micron = 1.333 baryes.

if p_0 is negligibly small compared to p_1 and p_2, the pressures at intervals t_1 and t_2 respectively. Thus S is measured in terms of volume per unit time, and by a speed of 1000 cm.^{3}/sec. is meant that under these conditions the pressure in a volume of 1000 cm.^{3} is reduced to 1/ϵth (= 0.3678) of its initial value in 1 second.

As shown by the investigations of M. Knudsen,[3] a tube offers a resistance to the flow of gas, which may be designated by $1/F$, where F is the "conductivity." At very low pressures (mean free path of approximately the same value as the tube diameter) F is determined (for a tube of circular cross section) by the relation

$$\frac{1}{F} = \left(\frac{2.394}{D^3} L + \frac{3.184}{D^2} \right) \sqrt{\rho_1}. \tag{3}$$

In this equation L and D denote the length and diameter of the tube, respectively, while ρ_1 denotes the density at a pressure of 1 barye and absolute temperature T, and is determined by the relation

$$\rho_1 = \frac{M}{83.15 \times 10^6 T}, \tag{4}$$

where M = molecular weight of gas.

The term involving D^{-3} in equation (3) gives the effect of the length, while that involving D^{-2} represents the end effect. Thus for small values of D and large values of L, F varies approximately directly as D^3 and inversely as L. The curves in Fig. 1 represent plots of equation (3), applied to air at 20° C., drawn on log-log scale,[4] and give F as a function of L, for values of D indicated at the bottom of the figure. The linear portion of each curve represents the effect of the L/D^3 term in equation (3), while the curved portion represents the added effect of the term containing D^{-2}.

From equation (3) it follows that for the same dimensions of tube the rate of flow of hydrogen as compared with that of air is in the ratio $\sqrt{29/2} = 3.8$ approximately.

---

[3] (6) *Ann. Phys.*, 28, 75, 999 (1908); also references 1 to 5 in footnote 1.

[4] These plots were drawn up by Mr. J. H. Payne for use in connection with his investigations on the design of high speed pumps.

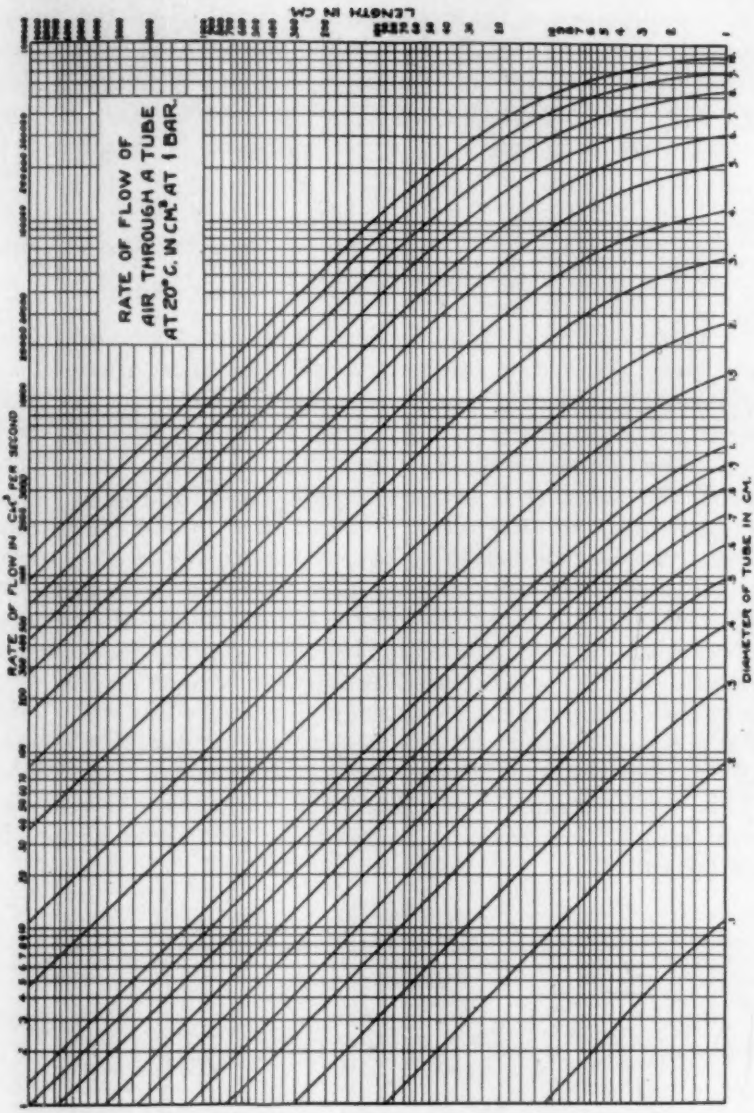


FIG. 1.

Rate of flow of air through a tube at 20° C. in cm.³ at one barye.

In consequence of this resistance to flow of gas offered by connecting tubes, the actual speed of exhaust (E) depends upon the values of both the intrinsic speed, S, of the pump, and the conductivity, F, the relation between the three quantities being given by an expression of the same form as that used for electrical resistances in series, that is,

$$\frac{1}{E} = \frac{1}{S} + \frac{1}{F} \tag{6}$$

or

$$E = \frac{SF}{S + F}.$$

Thus, assuming pumps having speeds S of 5,000 and 20,000 cm.^{3}/sec., the actual values of E which may be obtained for different values of F are those given in Table I. As these figures indicate, the effect of a large value of S becomes more and more inappreciable as F is decreased, so that for low values of F, the value of E becomes independent of that of S and approaches the value of F. Hence it is important for the advantageous utilization of the maximum speed of a pump that proper care be taken to make F as large as practicable. On the other hand, these considerations lead to the obvious conclusion that where the dimensions of connecting tubes are determined by other considerations, so that F is not very large, it is futile to use an extremely high speed pump. Thus for $F = 500$ ($L = 23$ cm., $D = 1$ cm.) a pump having a value $S = 5{,}000$ is almost as good as a pump for which $S = 20{,}000$. This matter requires special attention when liquid air traps are designed for insertion between the pump and system to be exhausted.

TABLE I.

Speeds of Exhaust for Different Values of F.

F.	E for $S = 5{,}000$.	E for $S = 20{,}000$.
∞	5,000	20,000
20,000	4,000	10,000
10,000	3,333	6,667
5,000	2,500	4,000
2,500	1,667	2,222
1,000	833	952
500	454	488

METHOD OF MEASURING SPEED OF PUMP.[5]

The method most generally used for measuring the speed of a pump depends on the application of equation (3). A capillary tube calibrated by use of this equation is inserted between a reservoir maintained at a constant pressure P_2 (which may be read on a McLeod gauge) and the pump. The pressure P_1 immediately at the opening to the latter is

FIG. 2.

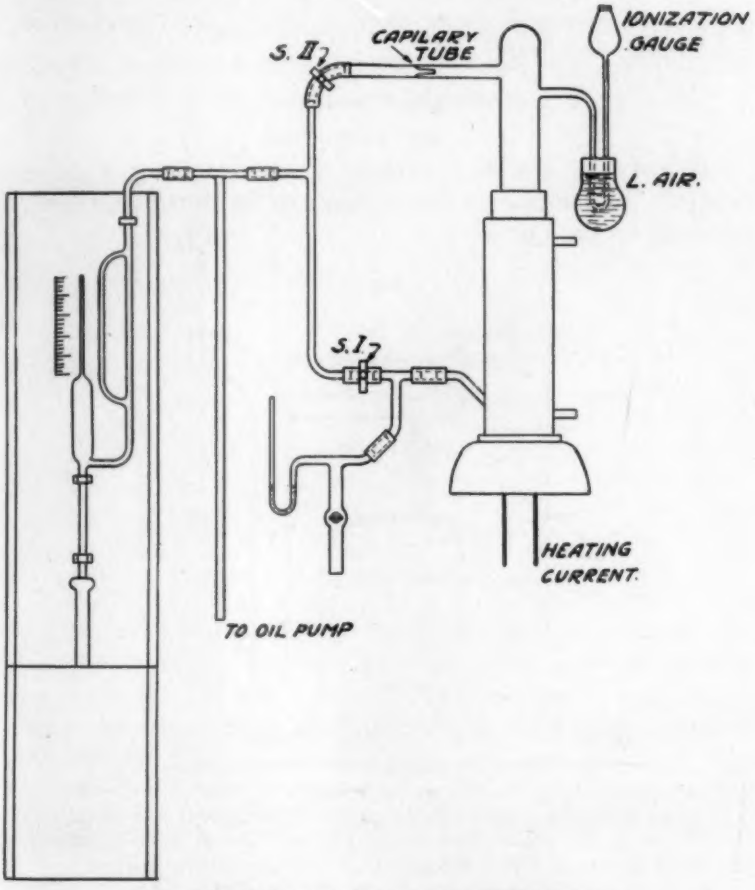


Diagram illustrating method of measuring speed of pumps.

[5] See reference 3, Chapter 10.

determined by an ionization gauge or other type of gauge capable of measuring very low pressures. The speed, S, is given by the relation

$$S = K\left(\frac{P_2 - P_1}{P_1}\right),$$

where K is the "constant" of the capillary. Figure 2 represents a diagrammatic sketch of the arrangement used by Mr. J. H. Payne in his investigations on the speed of the various designs of mercury vapor pumps which are described in a subsequent section.

MERCURY VAPOR PUMPS.[6]

(1) Gaede Diffusion Pump.

In 1915 W. Gaede published a description of a diffusion pump.[7] The action of this pump can be illustrated best by referring to Fig. 3.

FIG. 3.

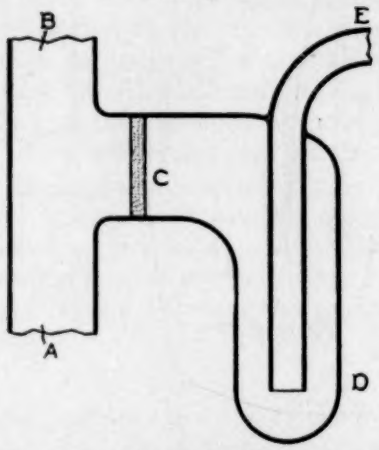


Diagram illustrating principle of diffusion pump.

[6] More detailed discussion of the earlier investigations and descriptions of various pumps will be found in the treatises on vacuum technique mentioned previously (references 1 to 5, footnote 1), also in the following papers:

(7) A. Gehrts, *Naturwissenschaften*, 7, 983 (1919).

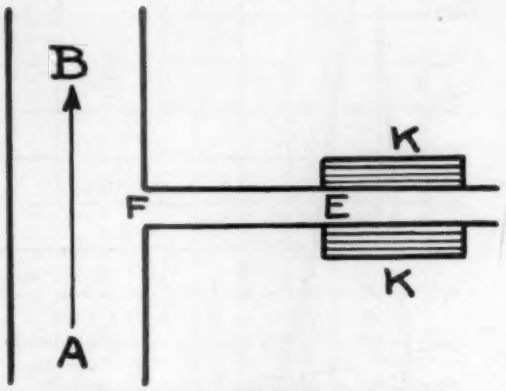
(8) W. Gaede, *Zeits. f. technische Physik*, 4, 337 (1923).

[7] (9) *Ann. Physik*, 46, 357–392 (1915).

"A blast of steam is blown through the tube, AB, in which is fixed a porous diaphragm C. The vessel to be exhausted is attached at E. Water vapor diffuses through the capillaries in the diaphragm into the trap D where it is condensed by some refrigerating agent, while air diffuses through the diaphragm in the opposite direction into the tube AB, from which it is drawn away rapidly by the blast of steam. The result is that the pressure in E decreases and finally reaches a very low value."

The speed of exhaust as a function of the pressure of the vapor and dimensions of the capillaries was deduced by Gaede from a consideration of the simple case illustrated in Fig. 4.

FIG. 4.



Diffusion through capillary into blast of vapor.

AB represents, as in Fig. 3, the blast of vapor, while EF represents a single capillary tube which is kept cool at the point E by the cooling jacket K. Consequently any molecules of the vapor diffusing into the side tube are condensed on the wall at E.

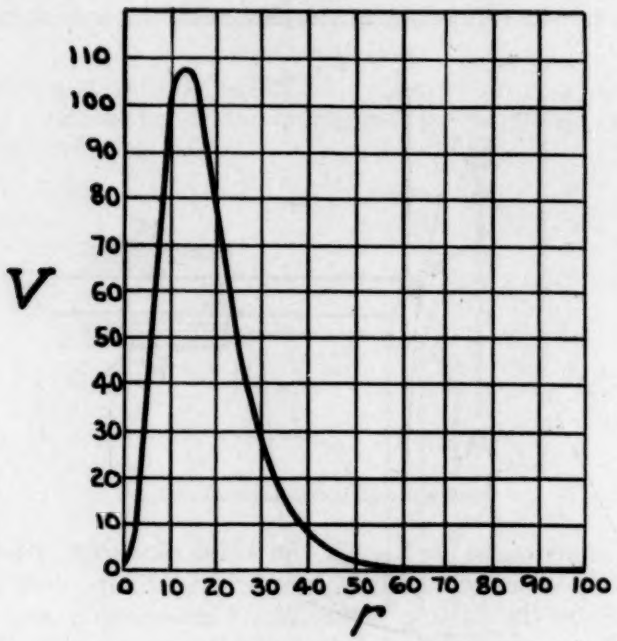
A calculation of the diffusion process leads Gaede to the following relation for the volume V of gas which diffuses per second through the opening F into the vapor:

$$V = \frac{I}{L}\frac{\pi r^3}{2\eta_1}\epsilon^{-rP/1520D\eta_2},$$

where L = length of tube EF,
r = radius of tube EF,
η_1 = coefficient of viscosity of gas,
η_2 = coefficient of viscosity of vapor,
D = coefficient of diffusion of gas,
P = pressure of vapor at F.

Figure 5 shows a plot of V against r, and it is observed that for large values of r, $V = 0$, while a sharp maximum is

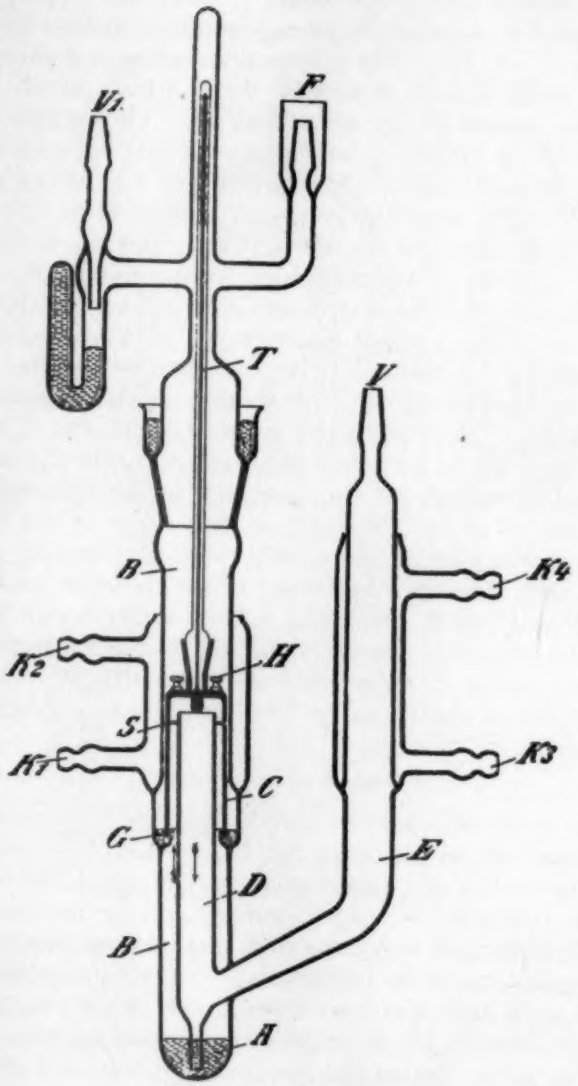
FIG. 5.



Speed of exhaust by diffusion through capillary.

obtained as r is decreased. Furthermore equation (7) shows that the speed depends upon the vapor pressure P and in order to reduce the exponential factor to approximately unity, r must vary inversely as P. Hence for large values of the vapor pressure, r must be made extremely small. However, the equation also shows that the speed of exhaust is independent

FIG. 6.



Original Gaede diffusion pump.

of the pressure of residual gas. In this respect Gaede's diffusion pump represented a distinct advance on mechanical types of pumps used previously.

The earliest form of diffusion pump constructed by Gaede is shown in Fig. 6. "The porous diaphragm is replaced by a steel cylinder C with a narrow slit S whose width can be altered by means of the set screws H. The cylinder is set in the mercury trough, G, which forms a seal between the low and high pressure parts. The mercury at A is heated and the stream of vapor passes over the slit in the steel cylinder in the direction indicated by the arrows. The air or other gas from the system to be exhausted (connected at F) diffuses into this mercury stream at S, and then passes out through E into the fore pump which is connected at V. Any mercury vapor passing out through S is condensed on the glass in the immediate neighborhood, by means of the water-cooling jacket K_1K_2. The opening V connects with the fore pump and is used for exhausting the system until the pressure becomes low enough for the operation of the diffusion pump to become effective. As soon as this stage is reached the mercury in the trap automatically closes the opening and the exhaust then continues by means of the diffusion pump." [8]

With this pump, operating against a fore-pump pressure of about 0.05 mm., speeds could be obtained varying from 50 to 200 cm.^{3}/sec., depending on the width of S, and the temperature of the mercury (indicated by the thermometer T in Fig. 6).

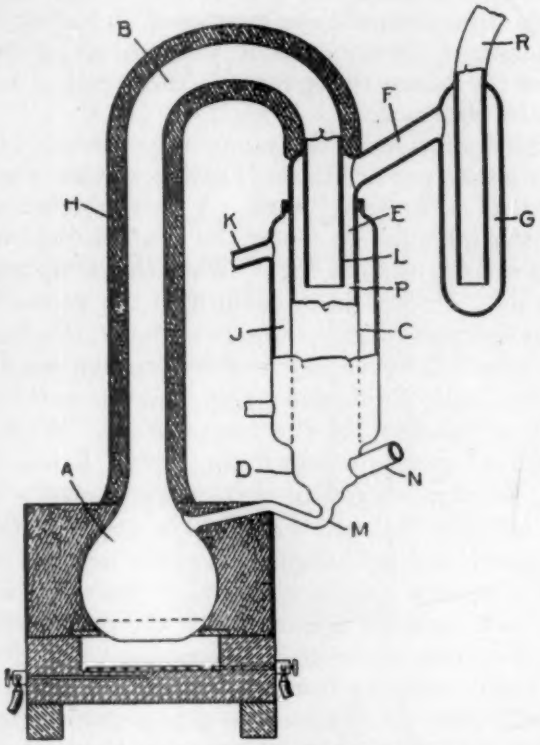
(2) Langmuir Condensation Pump.

As a result of a series of investigations which Langmuir had carried out on the condensation, evaporation and reflection of molecules at various surfaces,[9] he concluded that the speed of the mercury vapor pump could be increased considerably if the gas molecules diffusing in from the system to be exhausted could be imparted a velocity component by collision with high speed mercury atoms at the jet, and if at the same time the latter could be condensed rapidly, as they strike the walls, they would be prevented from diffusing back

[8] Quoted from p. 59, reference 4.
[9] *Phys. Rev.*, 8, 149 (1916).

into the system. An early form of glass condensation pump based on this principle is shown in Fig. 7. The following description of the construction and operation of this pump is taken from Langmuir's paper.[10]

FIG. 7.



Langmuir condensation pump, original glass form.

"In order that the pump may function properly it is essential that the end of the nozzle *L* shall be located below the level at which the water stands in the condenser *J*. In other words, the overflow tube *K* must be placed at a somewhat higher level than the lower end of the nozzle as is indicated in the figure. The other dimensions of the pump are of relative unimportance. The distance between *L* and *D* must

[10] *General Electric Review*, 1916, p. 1060; JR. FRANK. INST., **182**, 719 (1916).

be sufficiently great so that no perceptible quantity of gas can diffuse back against the blast of mercury vapor, and so that a large enough condensing area is furnished.

"The pump may be made in any suitable size. Some have been constructed in which the tube *B* and the nozzle *L* were one and a quarter inches in diameter while in the other pumps this tube was only one quarter of an inch in diameter, and the length of the whole pump was only about four inches. The larger the pump the greater is the speed of exhaustion that may be obtained.

"In the operation of the pump the mercury boiler *A* is heated by either gas or electric heating so that the mercury evaporates at a moderate rate. A thermometer placed in contact with the tube *B*, under the heat insulation, usually reads between 100 and 120 deg. C. when the pump is operating satisfactorily. Under these conditions the mercury in the boiler *A* evaporates quietly from its surface. No bubbles are formed, so there is never any tendency to bumping.

"Unlike Gaede's diffusion pump, there is nothing critical about the adjustment of the temperature. With an electrically heated pump in which the nozzle *L* was 7/8 in. in diameter, the pump began to operate satisfactorily when the heating unit delivered 220 watts. The speed of exhaustion remains practically unchanged when the heating current is increased even to a point where about 550 watts is applied.

"The back pressure against which the pump will operate depends, however, upon the amount and velocity of the mercury vapor escaping from the nozzle. Thus in the case above cited, with 220 watts, the pump would not operate with a back pressure exceeding about 50 bars, whereas with 550 watts back pressures as high as 800 bars did not affect the operation of the pump."

For technical operation, a metal form of condensation pump was developed, which is shown diagrammatically in Fig. 8.

"A metal cylinder *A* is provided with two openings *B* and *C*, of which *B* is connected to the backing pump and *C* to the vessel to be exhausted. Inside of the cylinder is a funnel-shaped tube *F* which rests on the bottom of the cylinder *A*.

Suspended from the top of the cylinder is a cup *E* inverted over the upper end of *F*. A water jacket, *J*, surrounds the walls of the cylinder, *A*, from the level, *B*, to a point somewhat above the lower edge of the cup *E*.

"Mercury is placed in the cylinder as indicated at *D*. By applying heat to the bottom of the cylinder, the mercury is caused to evaporate. The vapor passes up through *F*, is deflected by *E*, and is thus directed downward and outward against the water cooled walls of *A*. The gas entering at *C*

FIG. 8.

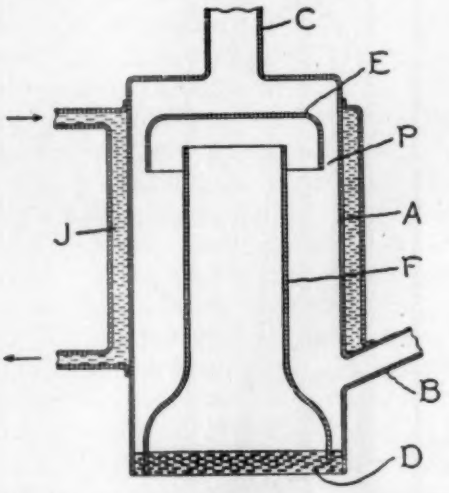
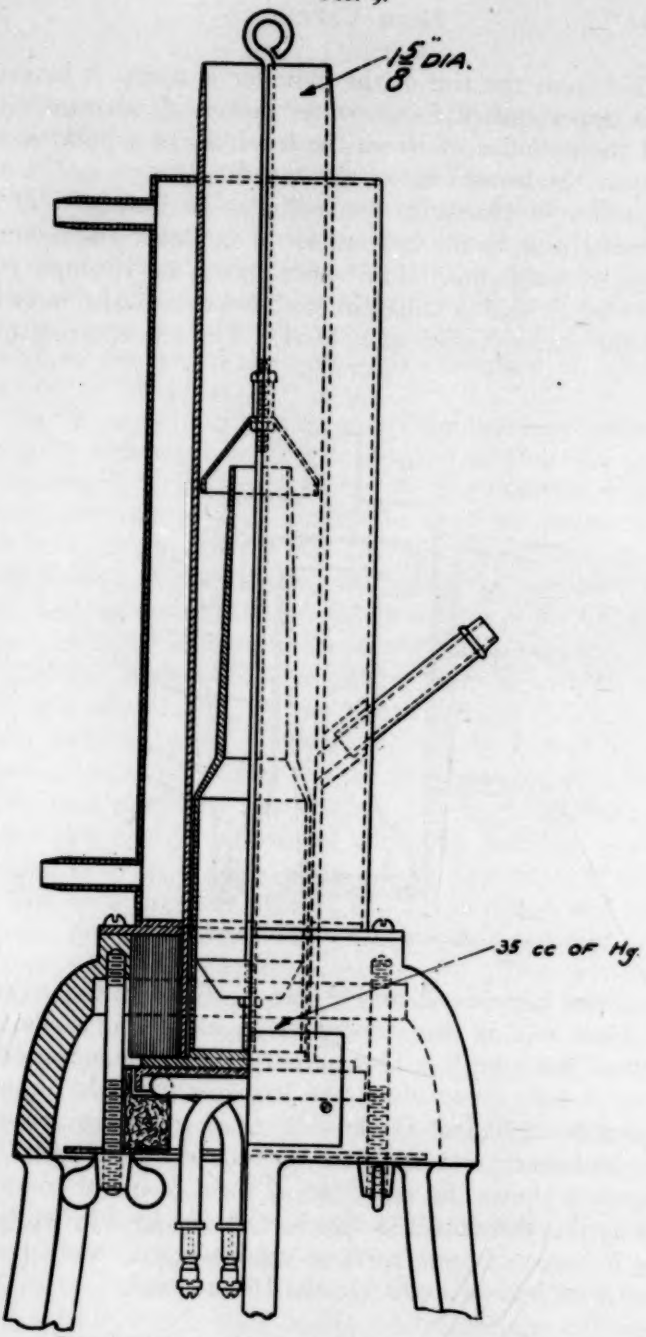


Diagram of construction of condensation pump (metal form).

passes down between *A* and *E* and at *P* meets the mercury vapor blast and is thus forced down along the walls of *A* and out of the tube *B*. The mercury which condenses on the walls of *A* falls down along the lower part of the funnel *F* and returns again to *D* through small openings provided where the funnel rests upon the bottom of the cylinder."

Figure 9 shows the most recent form of metal condensation pump as developed in this laboratory by Mr. McGraw. It has a speed of 5000 to 6000 cm.^{3} per sec., and operates against a back pressure as high as 100 microns.

FIG. 9.



Present modification of Langmuir single-stage pump (metal form).

(3) Multi-Stage Pumps.

While descriptions of modifications of both the Gaede and Langmuir single-stage mercury vapor pumps were subsequently published by different investigators,[11] the fact that these pumps required a relatively low backing pressure led to further developments in which this difficulty has been overcome.

As is well known, the commercial steam ejector is capable of reducing the pressure in a system to a moderately low value. Langmuir has pointed out that the ejector operates on a principle which is different from that utilized in the condensation pump. "The gas in the ejector," he states, "is sucked into the jet because *the pressure in the jet is lower than that of the gas in the vessel being exhausted.*" By operating with mercury vapor passing through fine nozzles it is possible, on this principle, to produce pressures sufficiently low for the operation of pumps of the type described in the previous section. From this it becomes a relatively simple matter to incorporate both stages in one pump.

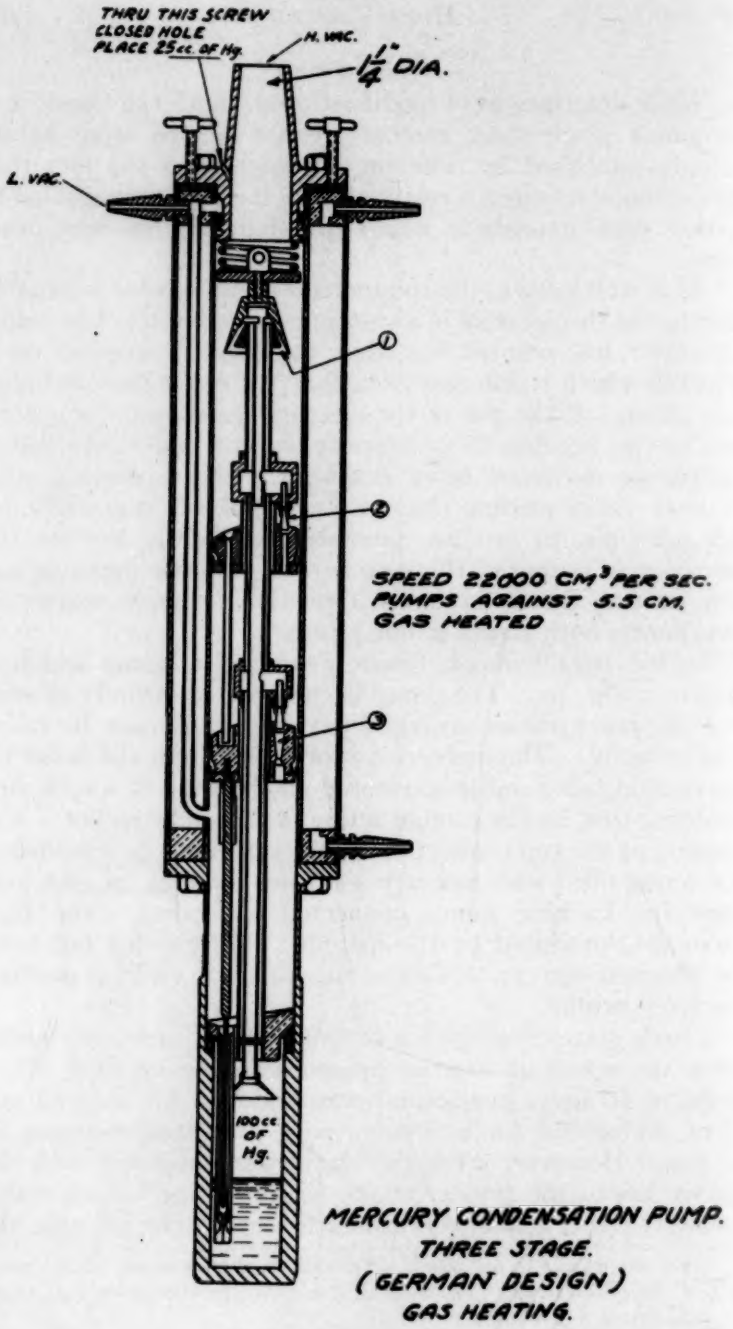
In his 1923 [12] paper, Gaede described a pump which is shown in Fig. 10. The pump is constructed entirely of steel and the parts are so arranged that the pump can be taken apart readily. The mercury vapor passes from the boiler up the central tube, and is condensed on the walls of a tube surrounding this, by the cooling action of the water jacket. The opening at the top connects with the system to be exhausted, and a ring filled with mercury separates the high vacuum side from the backing pump connected as shown. The high vacuum is produced by the mercury blast passing out from the inverted cup (1), while the nozzles at (2) and (3) produce the fore-vacuum.

Gaede states that with a pressure of 10^{-4} mm. and measuring the speed at a point adjacent to the opening (1), a speed of 60 liters per second was obtained for air and 100 liters per second for hydrogen, with a backing pressure of 20 mm. However, when the speed was measured with the connection to the system at the wide opening (which corresponds to the actual conditions for using the pump), the

[11] See references 4, 5, footnote 1. A discussion of more recent forms is given by K. C. D. Hickman and C. R. Sanford, *Rev. of Sci. Instruments*, **2**, 140 (1930).

[12] Reference 8 in footnote 6.

FIG. 10.



Gaede three-stage mercury pump.

added resistance of the tube between the opening and (1) reduced the result to *15,000 cm.³/sec. for air.*

Mention should be made here of two papers by W. Molthan [13] in which the theory of the action of the slits and nozzles in the Gaede diffusion pump has been discussed very comprehensively.

As in the case of the single stage pumps, a large number of different designs of two or three stage mercury vapor pumps has been described in the literature. In fact it may be stated that each laboratory has developed its own particular modification which it believes to be a distinct improvement over all other types. This remark applies especially to the design of pumps made of pyrex (Corning G 702 P or nonex), which can be operated at higher temperatures of the mercury boiler than is possible with pumps made of lead or lime glass.

A two stage pump made of pyrex has been described by E. K. Kurth, and Fig. 11 shows a variation of this construction designed by Mr. W. A. Ruggles in this laboratory. It has the great advantage that the glass blowing is not very difficult, while the speed of exhaust, ranging around 3000–4000 cm.³/sec., is sufficiently high for all laboratory purposes.

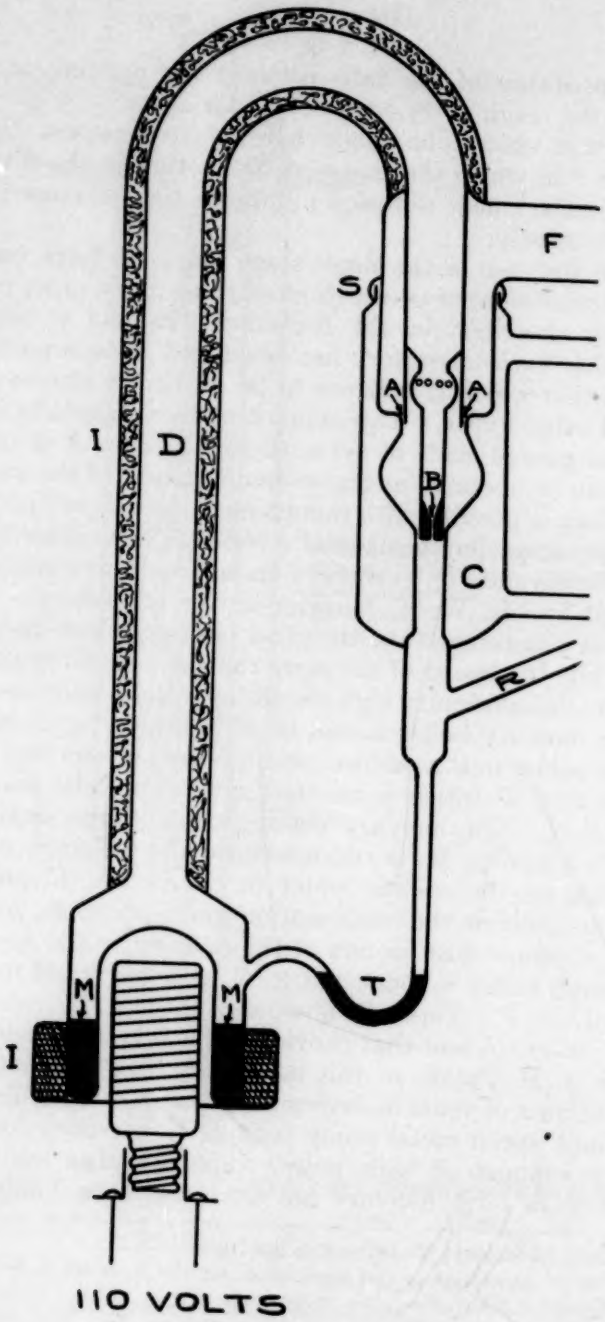
The mercury boiler shown at *M* is heated by a standard radiant heater unit as shown, and the blast of mercury passes up the tube *D* which is covered with some heat insulating material, *I*. The mercury passing through the small holes past the opening, *A*, is condensed on the adjacent parts of the walls by the cooling water in the jacket, *C*, and thus functions there on the condensation pump principle, while the higher pressure stage occurs at the opening to the nozzle, *B*. The rough pump is connected to *R*, and the vessel to be exhausted, at *F*. Tape, *S*, is wound around the top of the water jacket, *C*, and thus provides a flexible joint there.

Mr. J. H. Payne, of this laboratory, has been interested for a number of years in determining the most suitable design for a high-speed metal pump such as is necessary for use in factory exhaust of high power vacuum tubes and in the operation of large mercury arc rectifiers.[14] In Table II are

[13] *Zeits. f. technische Physik*, 7, 377, 452 (1926).

[14] For an illustration of this application, see the paper by A. W. Hull and H. D. Brown, *A.I.E.E. Proc.*, Jan. 26–30, 1931.

FIG. 11.



Two-stage mercury vapor pump, glass form.

shown observations made on different types of pumps by Messrs. C. T. DeGroat and R. F. Ockley, who have been associated with Mr. Payne in this work. The first column describes the type of design, and the other columns give under p_0 and p_1, the minimum pressure attained by the pump and the backing-up pressure respectively. The table also shows the power consumption for optimum operating conditions and the resulting speed of exhaust, S. Since pumps constructed apparently identically may exhibit variations in speed of as much as 50 per cent., the values given in the last column should be regarded as rough approximations to the average values of a large number of observations.

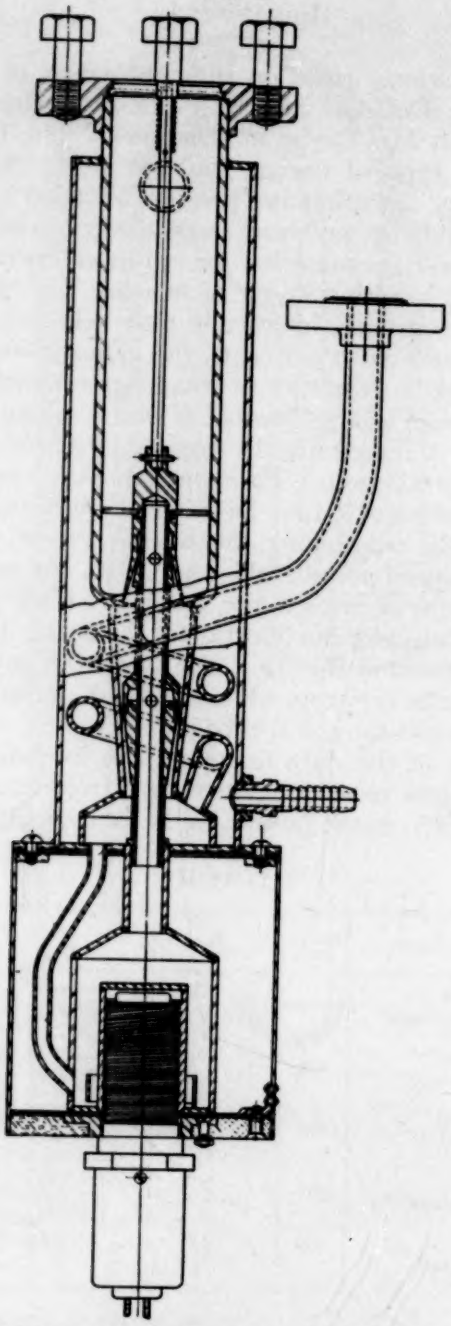
Pump no. 1 represents the original design of Langmuir's single stage metal pump. Pump no. 2 is a type manufactured by the Incandescent Lamp Division of the General Electric Company. By redesigning the nozzle, Payne was able to increase the speed considerably, as shown for no. 3. Pump no. 4 represents a preliminary design and no. 5 shows the result of a subsequent modification of the nozzle design. This last type is shown in Fig. 12. The system to be exhausted is connected at the very top, while the rough pump is connected to the opening of the spiral tube on the right.

As shown in the data under p_0, the minimum pressures obtained in these measurements ranged from 0.0002 to 0.0008 microns. With metal pumps, it is exceedingly difficult to

TABLE II

Number	Pump Type	Watts Input	p_1 mm.	p_0 microns	S cm.³/sec.
1	Langmuir (single stage)	300	0.10 to 0.01	.0005 to .0002	5,000 to 6,000
2	Cleveland (two stage)	365	1.0 to 5.0	.0004 to .0008	600 to 1,000
3	Cleveland (modified)	365	2.5 to 8.0	.0004 to .0008	3,000 to 4,000
4	Payne (two stage)	550	1.0 to 3.0	.0003 to .0007	12,000 to 15,500
5	Payne (modified)	550	2.0	.0003	60,000

FIG. 12.



Two-stage mercury condensation pump (Payne design).

obtain lower pressures because of inevitable slight leaks at connections and gas evolution from metal parts. On the other hand, by the use of glass pumps to which the system to be exhausted could be sealed on directly, Mr. Ruggles has been able to obtain pressures as low as 0.0001 micron.

Of course such low pressures can be obtained only by taking extra precautions to see that all sources of vapor in the exhaust system are completely eliminated. This result is obtained by a preliminary bake out of the tubes to as high a temperature as the glass will stand without collapsing. Even the glass connections from the tube to the liquid air trap must be torched or treated by other methods, such as a spark coil, to remove adsorbed water and other vapors from the walls. Stopcocks are not desirable in a vacuum system, not only because they reduce the speed of exhaust, but also because of their tendency to leak in spite of everything.

While formerly the constrictions on the tubes (necessary for seal-off purposes) were fine and thus reduced the exhaust speed considerably, it has become possible through added experience to seal off much larger constrictions and at present it is usual practice to seal on large power tubes with constrictions as large as ¼ inch inside diameter.

In the case of the metal parts used in tubes, the earlier practice consisted in bombarding them with electrons from the hot cathodes. Anode voltages as high as possible were used, while, in order to save the filaments, the electron current was kept relatively low, except for very short intervals of intensive bombardment. Within the past decade, treatment of metal parts has been replaced, at least in the initial stages of exhaust, by heating with high frequency current which is supplied by a portable 5 or 10 KW. oscillator set. This method not only removes gases from the metal parts more quickly, but also saves the filament from chemical attack by water-vapor or positive ion bombardment—both of which were frequent causes of destruction of tubes in the former exhaust procedure. Moreover when bombarding with voltages as high as 50,000 volts or higher, puncturing of the glass would tend to occur, or arcing between electrodes, whenever large amounts of gas were liberated. By postponing the high voltage treatment to a stage at which most of the gas has

been removed previously by high frequency treatment, these possible causes of disaster are also eliminated.

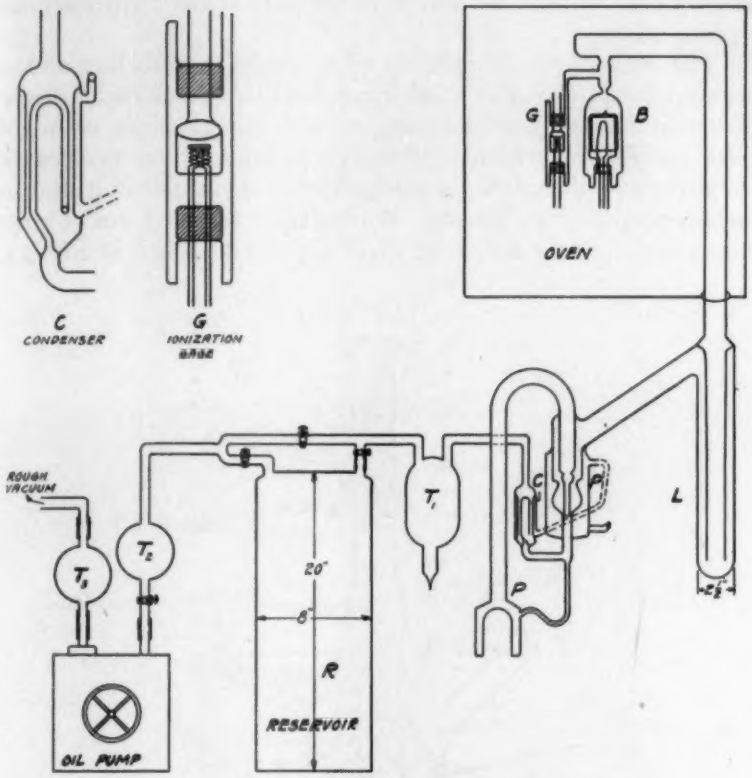
In a subsequent section the question of the nature and amounts of the gases contained in metal parts and further details regarding the conditions for removal of such gases will be discussed more fully.

One other feature of present-day exhaust methods is also worth noting. With the earlier types of condensation pumps requiring a backing up pressure of 0.25 mm., or even as low as 0.01 mm., it was necessary to operate an oil pump as fore pump and this in turn was backed up by a rough pump giving a vacuum of 2 to 5 cm. of mercury. The constant noise of these oil pumps was certainly not conducive to quietness in the laboratory or factory. With present-day two stage pumps operating against a backing pressure of 1 to 2 mm. of mercury, it is possible to operate a large number of these pumps on an exhaust pipe line which supplies the requisite vacuum and which in turn is connected to a large rotary oil pump located at a distance from the exhaust room.

A variation of this procedure which is much in favor in many factories consists in inserting a large reservoir between the mercury pump and an oil pump. The latter is then operated only for the relatively short period required to reduce the pressure to below 1 mm., and after that the reservoir alone is able to take care of the gas carried over by the mercury pump. An exhaust system of this form is shown in Fig. 13.

The tube to be exhausted (B) is connected through wide tubing (inside diameter = 1⅛ inch) to the liquid air trap L and to the pump P. A condenser, C, shown enlarged at the upper left hand corner, and trap, T_1, are inserted between the pump and the reservoir, R. The traps T_2 and T_3 are necessary to protect the vacuum system and rough vacuum line from the effects of the "backing-up" of oil. An ionization gauge, shown enlarged in the upper left-hand corner, forms a useful accessory to an exhaust system for indicating very low pressures, while a McLeod gauge may be connected between C and R to indicate the pressure on the rough side of the mercury pump.

FIG. 13.



Arrangement of typical exhaust system.

CONDENSATION PUMPS USING ORGANIC LIQUIDS.

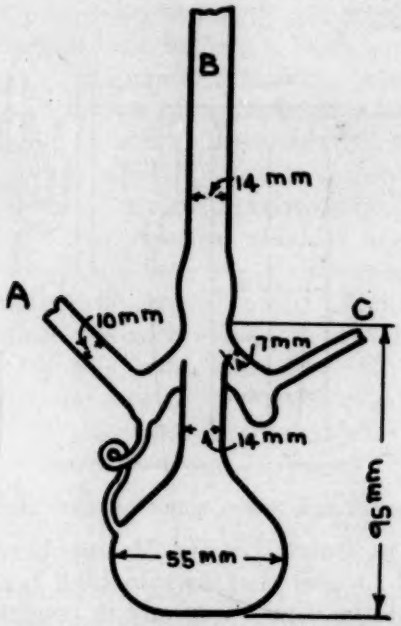
In 1928 C. R. Burch,[15] of the Metropolitan Vickers Electrical Co., Ltd., found that certain high boiling petroleum derivatives could be used effectively in condensation pumps. One such product is described by him as having a vapor pressure of 1 barye at 118° C. and capable of being heated without decomposition to a temperature corresponding to a pressure of 100 baryes. Using this liquid in a condensation pump, he was able to obtain a vacuum of 10^{-4} baryes, without the customary liquid air trap. As a result of this investigation

[15] *Nature*, **122**, 729 (1928)

there have been designed by the Metropolitan Vickers Company metal pumps in which these petroleum hydrocarbons replace mercury.

The suggestion of replacing mercury by organic liquids has been applied by K. C. D. Hickman and C. R. Sanford,[16] of the Eastman Kodak Laboratories, to the construction of small glass pumps in which *n*-di-butyl phthalate, or preferably butyl benzyl phthalate, is used instead of the paraffin hydrocarbon prepared by Burch. A relatively simple form of glass pump designed for use with these liquids is shown in Fig. 14.

FIG. 14.

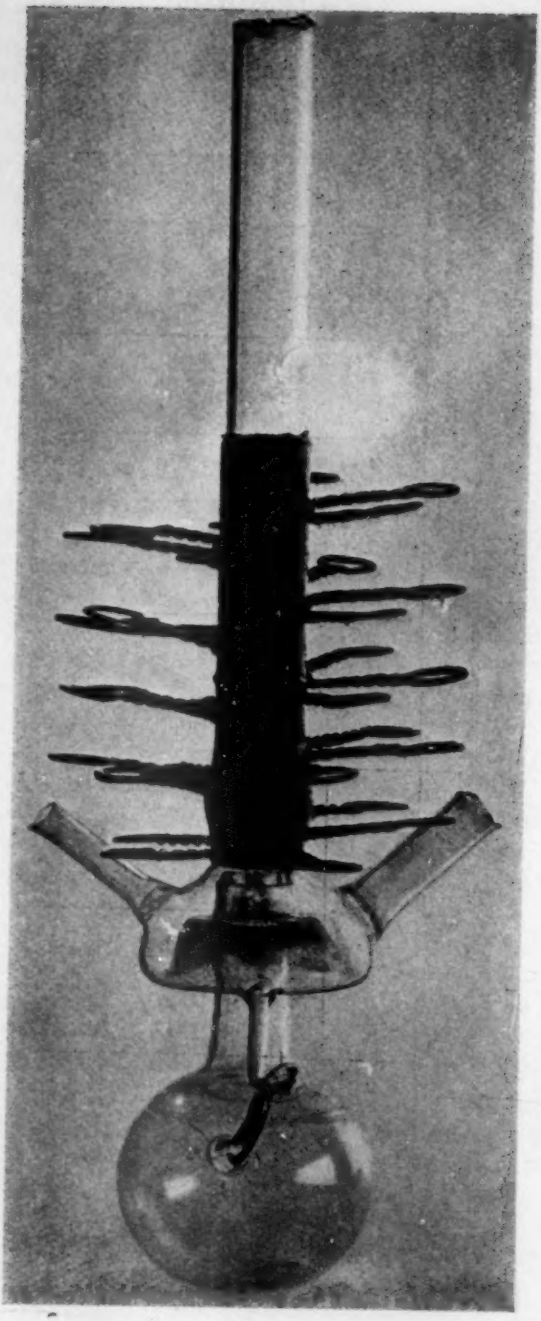


Glass pump (Hickman design) for use with organic liquids.

The opening *A* connects with the system to be exhausted, *C*, with a gauge, while the gas is discharged through *B*. Since the organic vapors leave the jet at temperatures from 35° to 100° C. higher than usual with mercury vapor, only a mild form of cooling is necessary, and with tubes of 1.5 cm., or less,

[16] See reference in footnote 11.

FIG. 15.



Hickman condensation pump using organic liquids.

TABLE III.

Liquid used in pump	Vapor pressure in mm. mercury		Still Air			With Fan Draught			Conditions under which pump is unaffected by variations in cooling	
	25° C.	0° C.	Watts input	Optimum speed cc. per second	Pressure at backing pump for opt. speed	Watts input	Optimum speed cc. per second	Pressure at backing pump for opt. speed	W.I.	O.S.
Mercury	2.3×10^{-3}	2.4×10^{-4}	40	7,000	0.15 mm.	60	8,000	0.20 mm.	45	6,500
Medicinal paraffin (Middle fraction)	10^{-5}	10^{-6}	35	2,000	.07 mm.	50	4,000	.10 mm.	—	—
N-di-butyl phthalate	7.8×10^{-5}	3.5×10^{-6}	32	6,500	.07 mm.	45	7,000	.09 mm.	35	6,000
Butyl benzyl phthalate	6.2×10^{-6}	2.6×10^{-7}	50	9,500	.07 mm.	70	10,000	.08 mm.	55	9,000
Fractionated rotary vacuum pump oil	$2.9\text{–}4.0\times10^{-6}$	$1.2\text{–}2.1\times10^{-7}$			0.6 mm.			.07 mm.	65	4,500

Hickman and Sanford find "that copper wire coiled and looped about the stem will produce excellent cooling." A photograph of a pump finished with wire is shown in Fig. 15.

Table III, taken from a paper by these investigators, gives data on the operation of such pumps with various organic vapors and for comparison results obtained with mercury. The last two columns headed W. I. and O. S. give the watt input and optimum speed respectively for satisfactory operation.

Hickman and Sanford make the following comment on the advantages of the use of phthalates in condensation pumps.

"The phthalates were found useful on account of good pumping speed, stability, the ease with which they could be obtained pure, and their low vapor pressures. Of the phthalates, butyl benzyl phthalate is the most efficient member of high boiling point, but is not easily obtainable. Failing this, *n*-di-butyl phthalate is recommended for use in diffusion pumps as a satisfactory substitute for mercury.

"For many purposes it does not require a refrigerant trap; and on other occasions a bath of ice and salt or solid carbon dioxide in acetone provides sufficient cooling. The optimum conditions under which it operates are narrowly defined but when once these are realized small pumps filled with this material will function perfectly without attention."

It is evident from this discussion that condensation pumps using organic liquids, such as those described above, will probably be found useful in many practical cases, especially where liquid air is not readily available.

SUBSTITUTES FOR LIQUID AIR.

In this connection mention should be made of an investigation by A. Ll. Hughes and F. E. Poindexter [17] on the possibility of using sodium and potassium as a trap for vapors of Hg, H_2O and CO_2, and thus eliminating the use of liquid air. The degree of vacuum, which they were able to obtain by this method as measured by an ionization gauge, was practically as high as that obtained by use of liquid air.

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[17] *Phil. Mag.*, 1, 423 (1925); also F. E. Poindexter, *J. Opt. Soc. A.*, 9, 629 (1924).

While the latter is undoubtedly the most effective means for eliminating condensable vapors, solid carbon dioxide ("dry ice") may be used fairly effectively for condensing mercury vapor, since the vapor pressure of the latter at $-78°$ C. (the temperature at which solid CO_2 has a vapor pressure of 1 atmosphere) is about 3×10^{-6} microns. However, since the vapor pressure of H_2O at this temperature is about 1 micron, it is absolutely essential under these conditions to heat the whole system as far as the condensation pump to a temperature of at least 360° C. If this procedure is not feasible, the rate of reduction of pressure in the system is limited by the rate at which water vapor can evaporate from the walls of the connecting tubes, and consequently, as the writer has observed, it may require a very considerable time to attain a good degree of vacuum.

In order to remove water vapor it has been customary in lamp practice to use P_2O_5. More recently other dehydrating agents have been produced [18] which are almost as effective and more convenient to handle. Undoubtedly these substances will find useful application in connection with many investigations in which it is desired to keep an exhaust system dry for prolonged periods.

II. USE OF GETTERS IN VACUUM TECHNIQUE.

By a "getter" is meant a reagent present in a vacuum device which improves the vacuum after seal-off from the exhaust system. The first such getter to be used in technical practice was phosphorus, suggested by Malignani in 1894 for use in carbon filament lamps. Subsequently F. Soddy proposed the volatilization of calcium as a method for removal of residual gases, thus reducing the pressure to a value below that attainable with an oil pump.

The large-scale production of hot cathode radio tubes would be impossible if it were not for the use of getters such as magnesium, calcium and other reagents which not only clean up residual gases left after seal-off but also maintain the

[18] The J. T. Baker Chemical Company has put out an anhydrous magnesium perchlorate ("anhydrone") and anhydrous barium perchlorate (desicchlora). See Yoe, McGahey and Smith, *J. Ind. and Eng. Chem.*, **20**, 656 (1928); Smith, *ibid.*, **19**, 411 (1927); and Yoe, *Chem. News*, **130**, 340 (1924).

degree of vacuum which is requisite for the efficient operation of the tubes during their life. In devices containing incandescent cathodes, residual gases may act deleteriously in two ways. Firstly, if the pressure is sufficiently high, so that the mean free path for an electron is of the same magnitude as the distance between anode and cathode, gas molecules are ionized by collision with the electrons. This leads to a partial or even complete elimination of space charge, and thus makes it impossible for the grid to function as a control on the amount of space current. Secondly, the electron emission from the cathode is decreased, either by formation of adsorbed monatomic layers of gas, or by positive ion bombardment of the emitting surface and consequent removal (by sputtering) of the material which is active in the emission of electrons.[19]

In order to prevent these deleterious effects, it is essential, in general, that the pressure in a radio tube be maintained at an extremely low value. For nitrogen at 25° C. the mean free path for an electron at 10^{-3} mm. is 42.5 cm., and the frequency of collision per cm. path is therefore about 0.002. Assuming that each collision results in ionization, one positive ion is formed per cm. length of path for 425 electrons. Since, however, one positive ion of nitrogen neutralizes the space charge effect due to 227 electrons, it follows that the residual pressure under these conditions would have to be at least ten times lower, or 10^{-5} mm. in order to prevent the elimination of space charge.

The electron emission from thoriated tungsten is extremely sensitive to traces of residual oxygen and it may be shown very readily that even at 2×10^{-6} mm. pressure, it would require only one second to cover a thorium film completely with oxygen molecules. Hence in order to obtain a life of several thousand hours, as is actually obtained with such filaments, the residual oxygen pressures must be less than 10^{-12} mm. of mercury, or approximately 10^{-15} atmosphere.

The theory of the action of various getters in cleaning up residual gases is not always understood thoroughly. In some cases the action may be regarded as purely chemical; compounds are formed between the volatilized metal and residual

[19] For detailed discussion of the effects of gases on emission see the review by the writer on "Thermionic Emission" in *Reviews of Modern Physics*, **2**, 381 (1930).

gases. In other cases the clean-up is aided materially by applying a potential between anode and cathode. Apparently the gas molecules are ionized or activated and react more readily under these conditions with the getter. Finally the getter deposited on the bulb walls may clean up residual gases by mere adsorption. Gas molecules striking the clean metal surface form there a monatomic layer of adsorbed molecules which, in consequence of an extremely low rate of reevaporation, is stable over quite a range of temperatures. It is thus necessary to distinguish between three different types of clean-up: (1) chemical, (2) electro-chemical, and (3) adsorption.

The reactions between tungsten at high temperatures and residual oxygen and nitrogen are typical of the chemical type of clean-up. In his investigations on the electron emission from thoriated tungsten, I. Langmuir obtained the requisite high degree of vacuum by operating a tungsten filament at temperatures around 2,900° K. with the bulb immersed in liquid air. Subsequent investigation with the ionization gauge have shown that the residual pressure attained by this method was 10^{-4} baryes, or less.[20]

Oxygen reacts with the tungsten on the surface and the WO_3 formed volatilizes and condenses on the walls. Nitrogen and carbon monoxide react with tungsten atoms in the gaseous phase with formation of WN_2 and WCO, while hydrogen is dissociated and cleaned up by the walls in the atomic condition.

The clean-up of gases at higher pressures by calcium, according to Soddy's process, is of the same type as the reaction between tungsten and nitrogen, but at lower pressures of residual gases the latter are removed either by adsorption on the metal film condensed on the walls, or by electro-chemical clean-up.

At a pressure of 10^{-3} mm. and 25° C. the mean free path for a molecule in nitrogen is 7.5 cm., and is therefore of the same order of magnitude as the customary dimensions of vacuum devices. Hence the majority of the molecules travel directly to the bulb walls and the frequency of collisions, in

[20] For details see references 1, 4 and 5, footnote 1; also I. Langmuir, *J. Am. Chem. Soc.* **37**, 1139 (1915); also *J. Ind. and Eng. Chem.*, **1**, 348 (1915).

the space becomes relatively small, as compared with the rate at which molecules strike the walls. In fact, a simple calculation shows that the ratio between the rate of incidence of molecules per unit area and frequency of collisions per unit volume is proportional to L/D, where D is the distance between walls and L is the mean free path. Thus at pressures below 10^{-3} mm., the rate of clean-up because of collisions between molecules in the space must become extremely small and any clean-up observed may be ascribed, in general, to adsorption of the residual gas molecules by the deposit on the walls.

While adsorption thus constitutes the most effective method for improving the vacuum at low initial pressures, electrochemical clean-up also occurs to some extent. In the manufacture of radio tubes, this type of clean-up is known as "aging by voltage," and is used extensively to improve the vacuum immediately after seal-off. Even without any getter, it is possible to decrease the pressure to some extent by drawing electrons of relatively high velocity (100 to 200 volts) from the cathode. That the ions thus formed by collisions between electrons and gas molecules are driven into the negatively charged walls seems fairly certain. The phosphorus clean-up in incandescent lamps has been investigated both in this laboratory by the writer and his associates and in that of the General Electric Company, Ltd., Wembley, England by N. R. Campbell and others.[21] While there is thus available a great deal of information in this field, the interpretation of these observations is, in general, still debatable.

Although activated charcoal at liquid air temperature is very efficient in reducing the pressure of gases, its use in sealed off devices is obviously impractical. It is of interest in this connection to note that in some recent experiments which Mr. J. S. Bacon carried out at the writer's suggestion, the pressure attained in an ionization gauge attached to a large tube containing well degassed charcoal and immersed in liquid air, was less than 5×10^{-9} mm. This represents

[21] In addition to the references given in reference 4, footnote 1, see the papers by N. R. Campbell in *Phil. Mag.*, **40**, 585 (1920); **41**, 685 (1921); **42**, 227 (1921); **43**, 914 (1922); **48**, 553 (1924); and *Trans. Am. Electrochem. Soc.*, **44**, 87 (1923).

about the highest degree of vacuum which we have actually measured. The initial pressure in this case at seal-off was about 10^{-5} mm.

For commercial devices it is necessary to use a getter which shall have a negligible vapor pressure and at the same time shall form an active surface on the bulb walls for the condensation of residual gases. As mentioned already, the getters ordinarily used are magnesium, calcium or similar metals. A small piece of the metal is fastened to the outside of the anode and after baking out the tube to remove water vapor and carbon dioxide adsorbed on the glass walls, the getter is volatilized by heating the anode with high frequency current. The exhaust is then continued for a short period to remove gases evolved by the heated metal and the bulb is sealed off. During aging and subsequently, the residual gas pressure decreases rapidly and finally attains a value of 10^{-5} to 10^{-6} mm. of mercury.

In some experiments carried out by C. A. Kidner and the writer in 1921,[22] it was observed that by the use of calcium the hydrogen pressure in a 500 cm.^{3} bulb was decreased in a few minutes from 1.5×10^{-3} to 5×10^{-4} mm. and in two hours more to 5×10^{-7} mm. The clean-up of hydrogen was investigated especially because in comparison with oxygen, nitrogen and carbon monoxide, it is the most difficult gas to eliminate.

Very recently Mrs. M. R. Andrews and Mr. J. Bacon,[23] in our laboratory, have carried out a systematic investigation on the behavior of different getters in sealed off tubes. A 40 watt lamp-bulb *A* (see Fig. 16) containing the getter was connected to an ionization gauge (*B*) of the type developed by Mr. C. G. Found and the writer some years ago.[24] The anode and leads of the gauge were of molybdenum and the filaments of tungsten, and all metal parts were thoroughly degassed while on the pump. A liquid air trap was used between pump and getter system and the getter volatilized slowly before seal-off.

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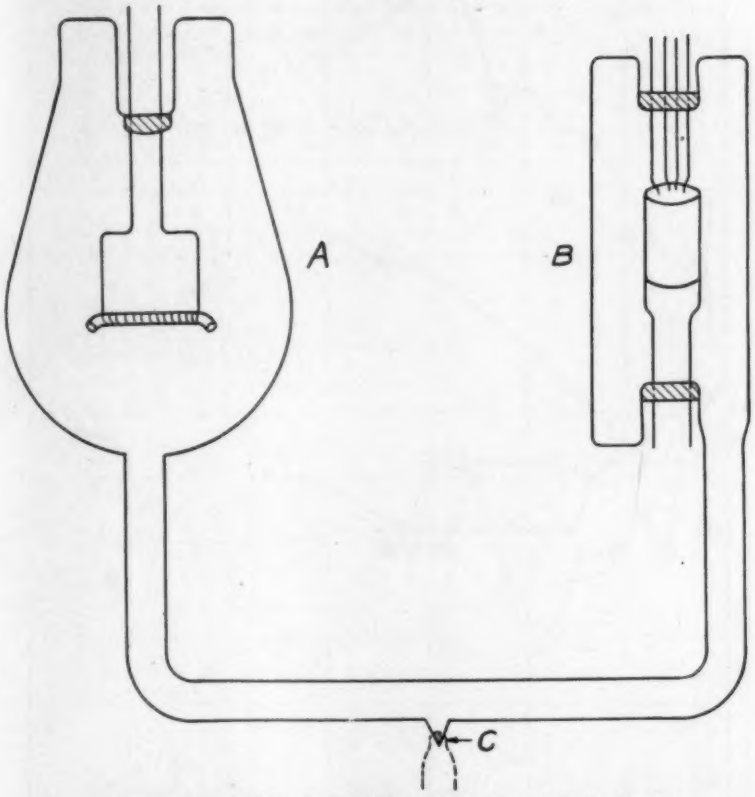
[22] Reference 4, footnote 1.

[23] Full details of these observations will be published in the May, 1931, number of the *Journ. of Am. Chem. Society.*

[24] *Phys. Rev.*, 17, 7; 23, 734.

Figure 17 shows results obtained with magnesium flashed by different methods. The upper curve shows the variation in pressure with time for a bulb without getter exhausted under the same conditions as the bulbs with getter. The next two lower curves were obtained with Mg flashed from

FIG. 16.

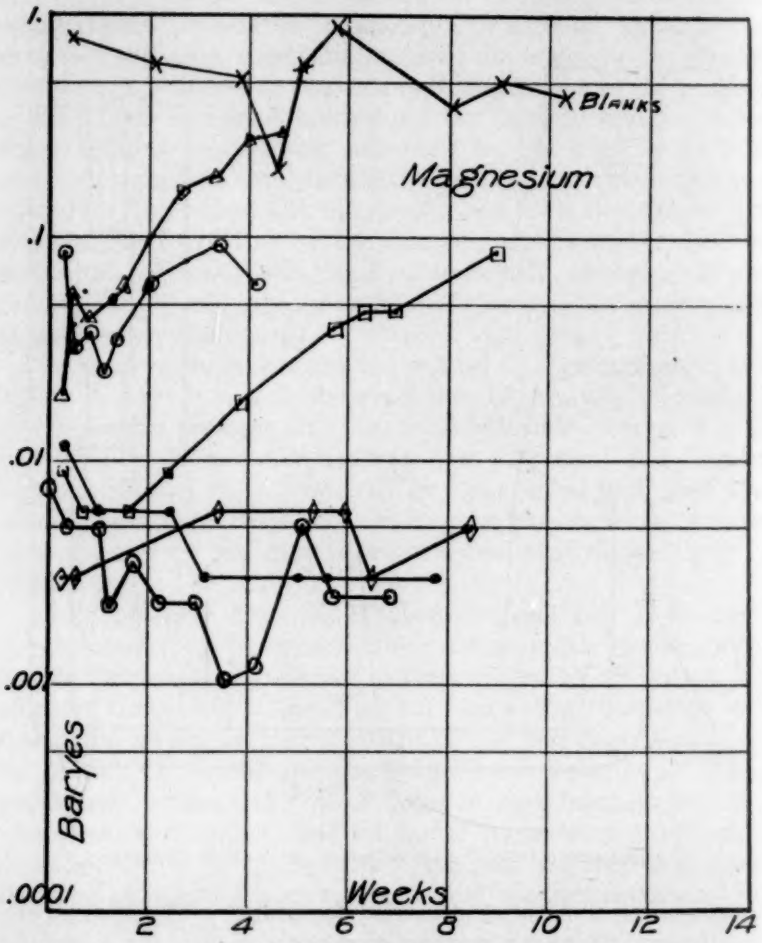


Arrangement of bulb and gauge for tests on getters (M. R. Andrews).

tungsten spiral without previous degassing. The curve running from 0.01 to 0.1 micron represents results for a sample of Mg degassed by operating the spiral at a red heat for about 15 minutes before the metal was vaporized. The three lowest curves were obtained with Mg in Mo envelopes and were thoroughly degassed before flashing.

The same difference between ordinary metal and degassed metal is illustrated in the curves in Fig. 18 for calcium. The two upper curves were obtained with metal which had been

FIG. 17.

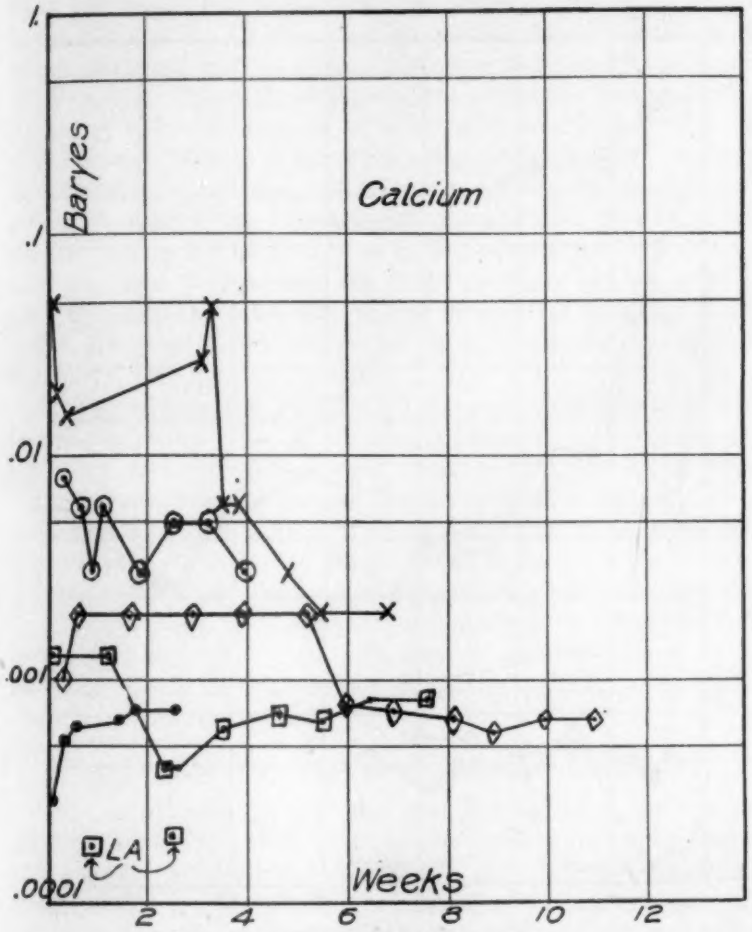


Effect of magnesium getter on vacuum.

degassed for 15 minutes in the spiral, while the three lower curves were obtained with metal which was vaporized for a period of two hours.

The behavior of sodium, illustrated in Fig. 19 is very interesting. The three upper curves were obtained with

FIG. 18.

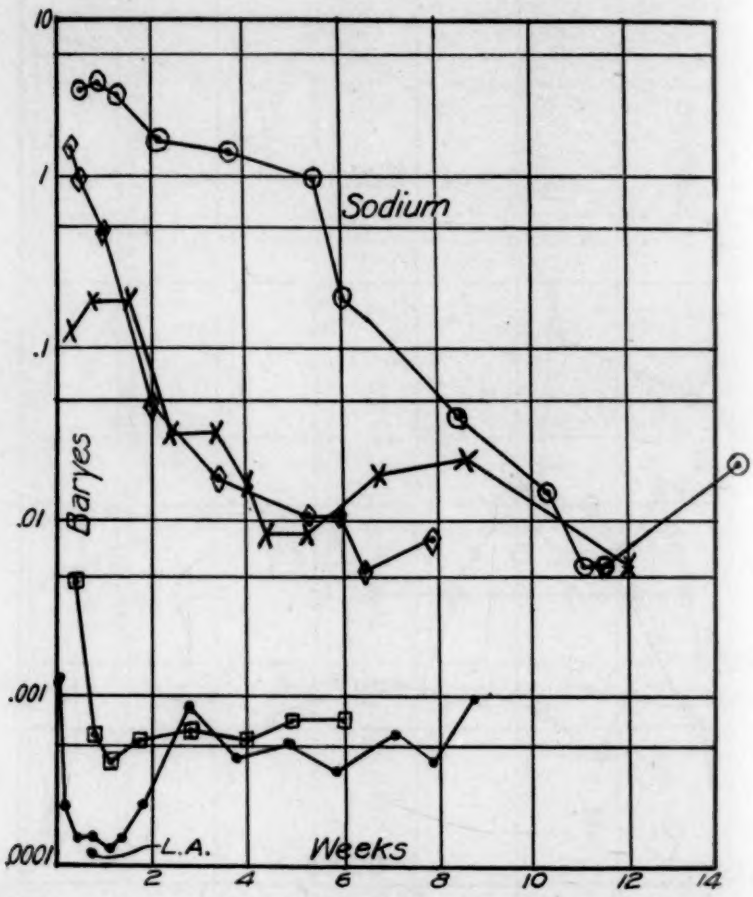


Effect of calcium getter on vacuum.

pellets consisting of NaCl + Ca in a metal case. On flashing these at high temperatures sodium is formed and condenses on the bulb wall. The lowest two curves were obtained with

metal formed on the bulb wall by electrolysis of the glass in the usual manner. Evidently the latter procedure produces a much more gas free metal and the resulting vacuum was much

FIG. 19.



Effect of sodium getter on vacuum.

better (.0001 to .001 micron) than with any of the other getters.

The order in which getters may be rated as clean-up reagents for most gases corresponds roughly to the chemical

activity. Thus cæsium is the most active metal, but its relatively high vapor pressure and ready tendency to produce positive ions prevent its extensive use. Sodium ranks next as a clean-up reagent, although even in that case the fact that the metal has an appreciable vapor pressure at 200° C. is an objection. Of the alkaline earth metals, barium is the most efficient, but is difficult to use because it is readily oxidizable. This difficulty has been overcome to some extent by using it in the form of an alloy with aluminum. On the other hand, calcium is not so readily oxidizable and is almost as efficient as barium. Magnesium cleans up oxygen to a pressure sufficiently low for the operation of thoriated filaments, but is not as active as the other getters for hydrogen and nitrogen. However, its freedom from oxidation in air and the relative ease with which it can be fastened to the anode have led to its general use in the manufacture of radio tubes.

Another material which has been recommended as a getter is mischmetal. This is an alloy obtained in the rare earth industry and contains 40 per cent. cerium while the other constituents are lanthanum (in largest amount) and other rare earth metals. As will be pointed out in a subsequent section, the rare earths absorb hydrogen strongly at room temperature and when heated to a high temperature they react vigorously with oxygen and nitrogen. Whether, however, this material is as effective or as convenient as the alkaline earth metals cannot be stated, since no published data are available.

III. GASES IN METALS AND VACUUM TREATED METALS.

As mentioned previously the development of vacuum devices has led to a realization of the importance of eliminating gases from metal parts. While this may be accomplished to some extent by high frequency heating during exhaust, it is often impossible or impracticable to use this method on account of the design of the tube. In such cases a preliminary treatment in a vacuum furnace or the use of vacuum fused metal has been found to be of great help.

A survey of the extensive literature on the subject of gases in metals shows that the gases may be present either in a

state of solution in the metal, or in the form of stable chemical compounds. Furthermore there is always present a certain amount of gas adsorbed on the surface. While the latter as well as gas in solution may be eliminated fairly readily by heating to below the fusion point, the gas present in the form of oxides or nitrides is more difficult to remove. In fact, in the case of the latter, vacuum fusion has been found to be the only really effective method.

The important part played by gases in metals in affecting their physical properties has also come to be recognized by the metallurgists and as a result a great many investigations on this subject have been carried out during the past few years. The problem has been studied regarding the origin of gases in metals, and other investigators have dealt with the solubility and diffusion of gases in metals. Since the conclusions reached are also of importance in the technique of vacuum production, it is of interest to review briefly the actual achievements in this field.

AMOUNT AND COMPOSITION OF GASES IN METALS.

In connection with his investigations on tungsten filament lamps, Dr. Langmuir developed a method for analyzing small amounts of gas contained in metals or glass.[25] He found [26] that when care is taken to remove water vapor and carbon dioxide from the glass walls, the amount of gas liberated from a tungsten filament does not exceed ten times the volume of the metal. Most of the gas is eliminated by heating the wire to 1,500° C. It consists of about 70 to 80 per cent. CO, the remainder being mostly H_2 and CO_2.

Using the same method, Mr. S. P. Sweetser in this laboratory determined the amount and composition of gases evolved by wires of other metals which are used in the construction of incandescent lamps.[27] The metals were in the form of filaments, having a total volume of about 0.03 cm.^{3}, so that they could be heated by passing current through them. Different samples of so-called "untreated" nickel wires gave off amounts of gas varying from 0.005 to 0.015 cm.^{3} of gas, consisting of

[25] *J. Am. Chem. Soc.*, 35, 105 (1912).
[26] *Trans. A.I.E.E.*, 32, 1921 (1913).
[27] Reference 4, footnote 1.

about 75 to 90 per cent. CO and 20 to 10 per cent. CO_2, with small amounts of H_2. Similar filaments of monel metal, copper and copper coated nickel-iron alloy (used for leads in lead-glass stems) gave amounts of gas varying from 0.003 to 0.02 cm.³ of gas. The composition of the gas was approximately the same as that evolved from the nickel wires. It will be observed that in all these cases the volume of gas did not exceed that of the metal, but since even such a small amount of gas as .010 cm.³ in a 500 cm.³ bulb is sufficient to raise the pressure by 15.2×10^{-3} mm., the importance of removing this gas before sealing off is evident.

H. M. Ryder [28] modified Langmuir's method of analysis and determined by this method the nature and composition of the gases eliminated from untreated commercial copper heated in vacuo. The gases evolved, in order of decreasing amounts, were CO_2, CO, H_2O and N_2. From a sample having a volume of 1.31 cm.³ the total amount of gas evolved at temperatures below 750° C. was about 0.2 cm.³.

The gases in steel have been investigated by G. Alleman and C. J. Darlington.[29] Some typical results obtained in this investigation are shown in Table IV.

TABLE IV.
Gases Evolved from Steel.

Vol. of gas per gm. of metal	Vol. of gas per cm.³ of metal	Max. Temp. (° C.)	Analysis of Gas Collected				
			CO_2	O_2	CO	H_2	N_2
(1) 25.2 cm.³	197 cm.³	1468	0.13	2.08	59.8	18.18	19.81
(2) 18.6	146	1500	1.20	0	79.8	11.65	7.35
(3) 8.5	67	1100	0.68	1.57	26.15	43.40	28.20

The analyses of the three metal samples were as follows:

Sample	(1) and (2)	(3)
Per cent. Carbon	1.049	.084
Per cent. Silicon	.153	.005
Per cent. Phosphorus	.045	.094
Per cent. Sulphur	.028	.082
Per cent. Manganese	.405	.536

[28] *J. Am. Chem. Soc.*, 40, 1656 (1918); JR. FRANK. INST., 187, 508 (1919).

[29] JR. FRANK. INST., 185, 161, 333, 461 (1918). This paper contains a comprehensive review of previous investigations on gases in ferrous alloys.

Table V shows results of an analysis of the gases obtained from a Bessemer steel (0.1 per cent. carbon) at different temperatures. The total amount of gas evolved was 28.1 cm.^{3} per gram or 220 cm.^{3} per cm.^{3} of metal.

It will be observed that the hydrogen and carbon dioxide were evolved at 1,250° C. and lower, while the removal of nitrogen and oxygen required much higher temperatures. At the highest temperatures the metals were in a fused condition. Another interesting feature of these results is the relatively large total volume of gas evolved, as compared with the results for tungsten, nickel and copper already mentioned.

TABLE V.

Gas	At 1000° C.	At 1250° C.	At 1500° C.	At 1675° C.
CO_2.....	1.08	.62	.00	.00
O_2.....	2.4	3.07	4.28	6.25
CO.....	48.9	56.10	18.75	8.42
H_2.....	21.16	15.08	4.20	1.10
N_2.....	26.46	25.13	72.77	84.23

The large scale production and properties of vacuum fused metals have been discussed in a paper by W. Rohn.[30] He states that normally there is obtained from 1 kgm. of vacuum fused metal, e.g., iron or nickel, 2 to 3 liters of gas (measured at atmospheric pressure), and sometimes as much as 15 liters. This corresponds to a volume of gas which is 16 to 120 times that of the metal. The gas consists mostly of hydrogen and carbon monoxide, and is ascribed to chemical reactions which have not been completed in the production of the metal and which proceed to completion when the metal is heated to a high temperature in vacuo. Thus CO and CO_2 are due to a reaction between carbon in the metal and residual oxides, while H_2 is due to interaction between water vapor and the metals.

Regarding the temperatures at which gases are evolved, Rohn's observations on a chrome nickel alloy show that *most of the gas is evolved after the material is fused*, and that the gas then contains a relatively large proportion of CO with smaller

[30] *Zeits. f. Metallkunde*, 21, 12 (1929).

percentages of N_2, O_2 and H_2. However, most of the hydrogen is evolved at a temperature below 1000° C.

Incidentally, Rohn emphasizes the rapid progress which has been made in increasing the maximum size of ingot that can be cast in vacuo. The weights for ingots of chrome-nickel alloy fused and cast in vacuum for 1922, 1924 and 1926 are given as 40, 230 and 1,400 kgm., respectively. While no definite statement is made about the degree of vacuum under which this process is carried out, the diagrams in the original paper indicate that the pressure during fusion is about 10 mm.

Naturally the problem of developing precise methods for the fusion of metals in a vacuum and determining the nature and composition of evolved gases has received a great deal of attention. As the discussion of these methods is beyond the scope of the present paper, it will suffice to mention some of the results obtained by the various investigators. A very comprehensive review of the different methods has been given by W. Hessenbrucher.[31] Tables VI and VII show data obtained by him for copper and nickel.

TABLE VI.

Gases in Copper Treated at 1250° C.

Sample	Vol. of gas in cm.³ per 100 g. metal	Vol. of gas per cm.³ metal	Composition of gas in volume per cent.			
			SO_2	H_2	CO	N_2
Refined Cu(1)	2.72	0.24	58.2	7.90	19.50	14.40
Refined Cu(2)	1.46	0.13	85.7	7.43		6.87
Refined Cu(3)	1.79	0.16	33.9	28.55	37.55	
Refined Cu(4)	0.73	0.07	61.1	11.11	22.22	5.57
Electrolytic Cu ...	7.97	0.71	10.9	39.52	49.70	

TABLE VII.

Gases in Nickel Treated at 1470° C.

Sample	Vol. of gas in cm.³ per 100 g. metal	Vol. of gas per cm.³ metal	Composition of gas in volumetric per cent.			
			CO_2	CO	H_2	N_2
Cube nickel.....	482	42.9	2.30	90.0	3.50	4.20
"Mond" nickel...	113	10.1	2.92	72.4	24.70	
Electrolytic.....	7.88	0.7	0.00	21.1	78.9	

[31] *Zeits. f. Metallkunde*, 21, 46 (1929).

The gas samples (1) and (3) in Table VI were taken at the beginning of the casting, while (2) and (4) were taken at the end. The SO_2 evidently originates from the reaction

$$Cu_2S + 2\ Cu_2O = SO_2 + 6\ Cu$$

as has been pointed out by E. H. Schulze [32] in a discussion of the causes of occurrence of gases in metals.

In the case of electrolytic nickel, the large amount of hydrogen must be due to gas occluded by the metal during deposition.

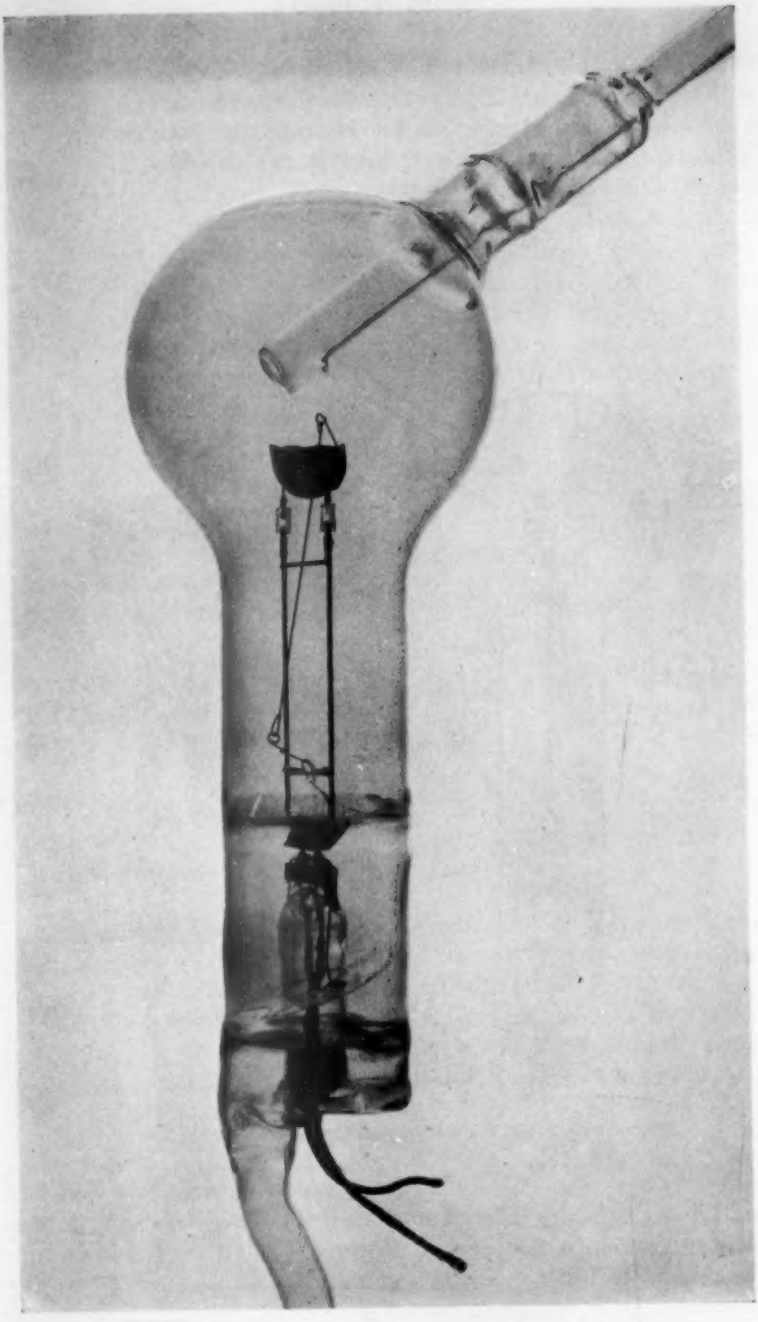
More recently A. Villachon and G. Chaudron [33] have reported results of an investigation on gases evolved from metals which had previously been fused in a vacuum furnace in which the pressure could be maintained at 0.02 mm. at about 1700° C. and 0.002 mm. at 1000° C. The metals were fused in magnesite crucibles, rolled down to thin sheets and then heated in tubes of pyrex or quartz to a temperature of 800° in the case of Ni, and 600° in that of Cu and Fe. The gas evolved consisted of H_2 and CO, and the total amount was approximately equal to that of the metal.

For many purposes a knowledge of the exact composition of the gas is not nearly so important as information about the total volume that may be removed by heating to a temperature just below fusion. On the basis of such data it is possible to compare the effects of different kinds of preliminary treatment of metal parts. In order to obtain such data, there was developed by Mrs. M. R. Andrews and students from the Massachusetts Institute of Technology who worked with her during vacations,[34] an apparatus shown in Figs. 20 and 21.

The first figure shows a 7-inch bulb in which was contained a molybdenum cup for heating the samples of metal. Gases evolved from the latter were pumped over by a condensation pump into a reservoir to which was connected a McLeod gauge. Thus the total amount of gas could be measured. By means of a liquid air trap below the reservoir a determination could also be made of the amount of gas not condensable

[32] *Zeits. f. Metallkunde*, **21**, 7 (1929).
[33] *Revue de Metallurgie*, **27**, 368 (1930).
[34] These were H. B. Ellison, J. A. St. Louis and G. J. Meyers.

FIG. 20.

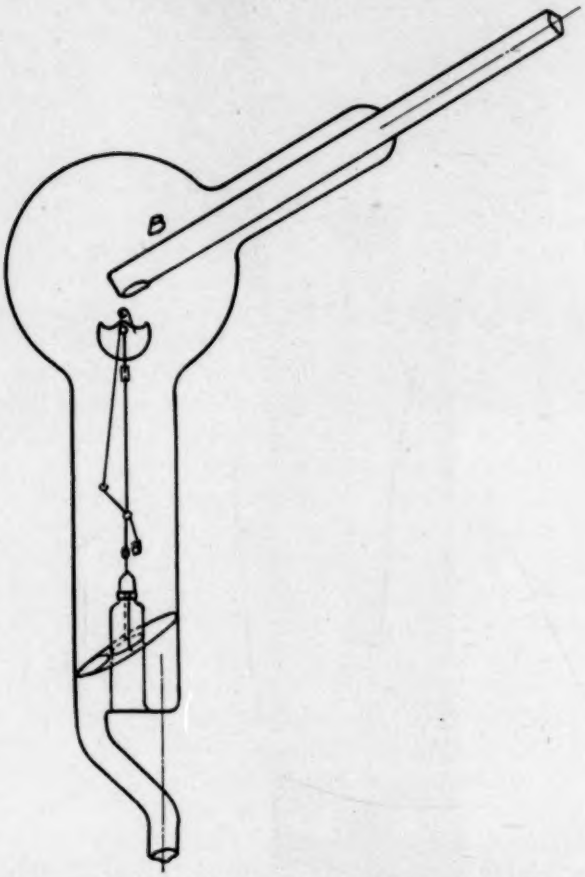


Bulb containing molybdenum cup for determination of gas in metals.

at liquid air temperature. This consists of H_2, N_2 and CO, while the condensable gas consists of H_2O and CO_2.

The procedure adopted for making an analysis consisted in placing the sample in the tube *B*. The whole system was

FIG. 21.



Diagrammatic sketch of arrangement for determination of gas in metals.

baked out at 450° C. for 1 hour, and the molybdenum cup heated with the high frequency to degas it. The sample was then shaken into the cup by tapping the tube *B* gently, and the reservoir for collecting evolved gas closed off from the

final pump. The high frequency was applied again, the temperature of the cup being determined by an optical pyrometer, and the heating continued until the gas evolution had become negligible at the maximum temperature.

Table VIII shows some typical results obtained by this method. Since the densities of both copper and nickel are approximately the same (8.9), 100 cm.³ per kgm. metal corresponds to 0.89 volume of gas per volume of metal. Thus the data show that the volume of gas rarely exceeded that of the metal and by treatment at high temperatures in vacuum the gas content could be reduced to less than 10 per cent. of the volume of the metal.

TABLE VIII.

Material	Non condensable gas in cm.³/kgm.	Condensable gas in cm.³/kgm.
Ni wire—.030″ H_2 annealed	49.0	3.1
	76.0	3.9
Ni strip—8 mil	60.2	8.2
Ni strip vacuum treated (1 hr. at 1000° C.)	40.5	5.5
Mo sheet	52.9	8.3
Mo sheet treated in H_2 (15 min. at 1150° C.)	10.8	4.0
Mo sheet heated in vacuum (1 hr. at 1050° C.)	9.8	3.7
Ni—H_2 annealed, diamond drawn	96.0	6.5
Cu—pure, deoxidized	12.1	2.5
	6.3	2.1
	2.5	1.6
Cu—heated to 1600° C. in vacuum	22.0	
	6.3	3.6
Cu boiled in vacuum in Mo cup	5.4	3.3

For some time Dr. A. L. Marshall, in our laboratory, has been degassing copper and other metals by actually boiling them in molybdenum tubes in an extremely good vacuum. While the complete details of the apparatus and method of analysis will be discussed by him in a forthcoming paper, Table IX gives a few of the results obtained. In the case of

TABLE IX.

Nature of sample	Vol. of gas in mm.³ per cm.³ metal: Surface gas	Interior gas
1. Electrolytic Cu	5.1	71
2. Commercial Cu	6.7	40
3. Vacuum fused Cu	9.1	36.8
4. Vacuum fused Cu	6.9	52

the copper samples, the "surface gas" corresponds to that evolved at temperatures of 1000° C. and lower, while the major portion of the interior gas was evolved during the volatilization of the metal.

The gas evolved consisted largely of CO with smaller amounts of H_2 and CO_2, except in the case of electrolytic copper where most of the surface gas was found to consist of H_2.

For samples of molybdenum heated to 2000° C. the volume of gas evolved varied from 37 to 75 mm.^{3}/cm.^{3}, and consisted of CO and N_2. It is of interest to observe that vacuum treated samples exposed to the atmosphere were observed to take up very little gas unless touched with the fingers. In the latter case, large amounts of CO were evolved rapidly on heating to 1600° C.

SORPTION OF GASES BY METALS.

The term "sorption" was suggested by J. W. McBain [35] as a "generic and non-hypothetical term for phenomena which frequently occur together," to include all cases in which the pressure of gases is reduced by metals, charcoal or other substances. The gases may be condensed on the surface, in which case the phenomenon is designated as *adsorption*, or they may actually enter the metal as a solute with the metals as solvent. The latter process is known as *absorption*. Also, the gases may combine chemically with the metal, as occurs in the sorption of oxygen and hydrogen by alkali metals. The term "sorption" comprises all these phenomena and is useful to indicate cases where the exact mechanism by which the metal takes up the gas is unknown.

The *adsorption* phenomena are extremely important from the point of view of the production of extremely low pressures. As mentioned previously, the behavior of most getters at low pressures is accounted for on the basis of surface condensation of residual gases. It was first shown by Langmuir [36] that in all cases of true adsorption the condensed gas forms a unimolecular layer. From a consideration of adsorption as the result of a kinetic equilibrium between rates of condensation

[35] *Phil. Mag.*, 18, 916 (1909); *Zeits. physikal. Chem.*, 68, 471 (1909).
[36] *J. Am. Chem. Soc.*, 40, 1361 (1918).

and of evaporation, Langmuir derived a simple relation between pressure and amount adsorbed, which is in good accord with actual observations. On this point of view the most important magnitude in connection with an adsorbed molecule is the "average life," that is, the reciprocal of the rate of evaporation. Thus for oxygen, adsorbed on mica, the life at 90° K. is 80,000 times greater than that of the molecules on the surface of liquid oxygen at the same temperature, and in all cases of adsorption the relative lives of the adsorbed atoms are thousands to millions times greater than for the liquids at the same temperature.

A relatively simple calculation shows that by adsorption alone it is theoretically possible to obtain appreciable reduction in pressure. Thus assuming a spherical bulb 5 cm. radius and molecules of a diameter 3×10^{-8} cm., the number of molecules required to form a unimolecular layer on the inside wall is 3.49×10^{17}, which corresponds to the number of molecules present in the bulb at a pressure of 93 microns. This would therefore be the maximum decrease in pressure if we had an absolutely clean surface before the gas is allowed to strike it. Thus the clean-up effects due to alkalies and alkaline earth metals are very readily accounted for.

While Langmuir derived his evidence for the presence of adsorbed layers from investigations with surface films on liquids, and from the chemical and physical behavior of metals in presence of gases at low pressures, there has been developed more recently a method (of an extremely novel type) for the investigation of surface films. Electrons are actually *shot at* a surface and an investigation of the characteristics of the reflected electrons serves to give the desired information about the nature and arrangement of the adsorbed atoms on the surface.

That electrons incident upon a metal surface behave in all respects like a wave motion with a wave-length inversely proportional to the velocity was shown by the investigations of Davisson and Germer, G. P. Thomson and E. Rupp. Hence electron beams may be used like X-rays to determine the lattice structure of crystals. However, it has been found that the most valuable application of this new discovery is the investigation of the structure of surface films.

The principle of the method used may be described briefly as follows: A beam of electrons of variable velocity is allowed to strike the surface to be examined at a definite angle of incidence and the intensity of the reflected beam is measured as a function of the voltage applied to the electrons. For certain definite voltages the intensity of the reflected beam exhibits maximum values and from the corresponding values of the voltage, the distance between atoms in the surface layer can be calculated by relations which are similar to those first used by Bragg in his determination of crystal structures by X-rays.

In this manner, Davisson and Germer [37] and E. Rupp [38] have studied the arrangement of gas atoms adsorbed on nickel and iron, and the method may thus make it possible to determine in detail the action of many getters used in vacuum technique.

The *absorption* of gases by metals has been investigated very comprehensively, especially by A. Sieverts,[39] of Jena. The solution of hydrogen in palladium, platinum and tantalum, and of oxygen in silver are typical of this class of phenomena.

One of the most interesting conclusions derived from the investigations in this field is that the amount of gas dissolved at constant temperature varies as the square root of the pressure. This holds valid for oxygen in molten silver as well as for hydrogen in practically all the metals with which it forms solutions.

The behavior of hydrogen with different metals is specially important. The solubility in silver, copper, nickel, cobalt and iron increases with temperature for both the solid and fused metals, with a rapid increase at the melting points. Figure 22 shows the isobars (solubility curves at atmospheric pressure) for copper, nickel and iron. The ordinates give amount of hydrogen absorbed (in mgm.) per 100 gr. metal. As will be mentioned subsequently, hydrogen diffuses readily

[37] *Phys. Rev.*, **31**, 307 (1928).

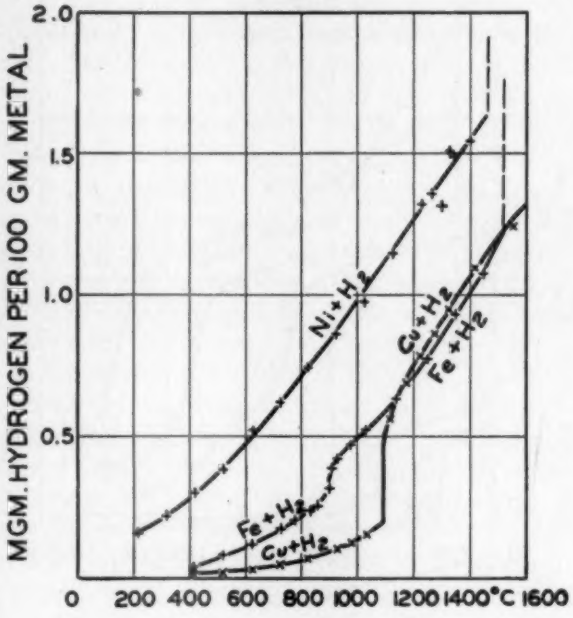
[38] *Zeits. f. Electrochem.*, **29**, 586 (1929).

[39] *Zs. f. Metallkunde*, **21**, 37 (1929). This gives a review of the results obtained for different metals and gases. See also reference 4, footnote 1, for literature to 1922.

through these metals. Also the amount dissolved at constant temperature varies as $p^{1/2}$.

The enormously high solubility of hydrogen in palladium, especially in the finely divided metal (palladium black), has been known for a long time. At 20° and atmospheric pressure, the metal can absorb from 670 to 800 volumes of hydro-

FIG. 22.



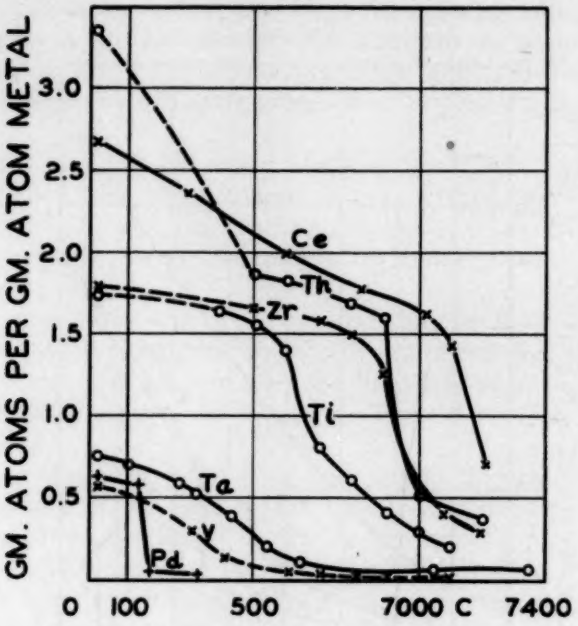
Solubility of hydrogen in nickel, copper and iron.

gen. With increase in temperature the solubility decreases; while at very low temperature the solubility is increased considerably.

With other metals such as Ta, V, Th, Ti and metals of the rare earth group, hydrogen also forms solutions which are semi-metallic in their properties. Figure 23 shows isobars at one atmosphere pressure for some of these metals as well as palladium over the range from 0° to 1400° C. Regarding these observations, Sieverts makes the following interesting statement. "In these hydrides containing extremely large

amounts of hydrogen (1 volume Ti dissolves 1800 volumes H_2, 1 volume Th, 1700 volumes H_2) there are present no chemical compounds, but, as is readily seen from a comparison of the isothermals at different temperatures, *solid solutions*."

FIG. 23.



Isobars for hydrogen in various metals.

The relative solubilities in the different metals at 20° and atmospheric pressures are shown in Table X.

TABLE X.

	Ti (1.7)	V (0.6)
	Zr (2.0)	Nb (0.7)
La (2.8) Ce (2.8)	Hf ?	Ta (0.8)
	Th 3.2	

With the alkali and alkaline earth metals hydrogen forms salt-like hydrides in which the hydrogen is present as a negative ion. These are stable at ordinary temperatures (dis-

sociation pressure for KH at 100° C. is 7.76×10^{-6} mm.)[40] but exhibit appreciable dissociation pressures at temperatures above 200° C.

With regard to the solubility of nitrogen in metals, little is known except in the case of iron. Sieverts states that between 900° and 1000° C., electrolytic iron takes up nitrogen slowly, and as much as 0.06 per cent. by weight of the gas has been introduced in this manner. Finely divided iron absorbs practically no nitrogen until a temperature of 900° C. is attained. At this point about 21 mgm. N_2 is taken up per 100 gr. iron. As the temperature is raised still further, the solubility decreases somewhat. On decreasing the temperature, the absorbed gas is re-evolved at 900°, so that the phenomenon is reversible. Furthermore the amount dissolved varies here also as $p^{1/2}$. The rapid increase in solubility at 900° is apparently connected with the transformation of the metal from the β to the γ modification.

For further details regarding the actual solubilities of various gases in the more common metals—the reader is referred to the tables at the end of Sieverts' paper.

The increased sorption of gases by metals in a finely divided condition has been known for a long time. The best illustration of this is the use of platinum and palladium black in both vacuum technique and investigations on catalysis. The absorption of H_2 and CO by pyrophoric Fe, Ni and CO has been investigated by N. Nikitin.[41] Hydrogen is very strongly absorbed by these powders at the temperature of liquid air. At $-80°$ C. and room temperature Fe does not absorb H_2, but as the temperature is raised to 380° C. and higher, the amount of gas absorbed increases again very rapidly. The hydrogen thus dissolved by iron powder is removed only very slowly by heating to 400° C. In the case of CO_2, iron powder absorbs the gas very readily at temperatures as high as 510° C. and in all cases it was observed that the amount absorbed varied with the pressure in accordance with Freundlich's equation

[40] Extrapolated from measurements of F. G. Keyes (*J. Am. Chem. Soc.*, **34**, 779, 1913) at temperatures above 300° C.

[41] *Z. f. anorg. Chem.*, **154**, 130 (1926).

$$\alpha = \beta p^{1/n}.$$

A discussion of this topic would be incomplete without some remarks on the results of some recent investigations on the diffusion of gases in metals.

Observations on the diffusion of hydrogen through different metals (Pd, Pt, Fe, Ni and Cu) have been reported by G. Borelius and S. Lindblom.[42] They observed that the rate of diffusion (m) as a function of the temperature is given by the relation

$$m = A\epsilon^{-Q/(RT)}$$

with values of Q, the heat of diffusion per gram molecule, ranging from 9400 cal. for Fe to 19,400 cal. for Pt. Furthermore, at constant temperature the rate of diffusion was found to vary linearly with p.

Similar results on the variation of rate of diffusion with pressure and temperature have been obtained by V. Lombard[43] for the diffusion of H_2 through Ni, Fe and Pt. It was also observed that while the rates of diffusion of N_2, A and He through Ni are low compared with that of H_2, they are not negligibly small.

This last result is in agreement with some observations which have been made on the solubility of the rare gases in metals. Although Sieverts concluded that these gases are insoluble in metals, V. Lombard finds a measurable solubility.

Finally mention should be made of the bearing of these observations on gases in metals on the choice of materials for anodes in radio tubes. The higher the temperature to which a metal may be raised in vacuum, the greater the amount of degassing. Consequently tungsten, molybdenum and tantalum are most preferable for use in the construction of anodes which are intended to operate at higher temperatures. In this country the tendency therefore has been towards the use of molybdenum because it can be rolled more easily and machined fairly readily. In Europe, on the other hand, tantalum has been used extensively, because of its clean-up action on hydrogen and other gases. Hence for high power

[42] *Ann. d. Physik*, **82**, 201 (1926).

[43] *Revue de Metallurgie*, **26**, 343 (1929). This gives a good bibliography of previous investigations.

tubes each of these materials has been utilized a great deal. For radio tubes of low watt output and for receiving tubes, nickel and magnesium getter are used because of the much lower cost of this metal as compared with either Mo or Ta. But in this case it is evident that pretreatment of the nickel in a vacuum furnace is of advantage in decreasing both the subsequent gas evolution during exhaust of the finished tube and the amount of gas which the getter has to clean up.

IV. MANOMETERS FOR MEASUREMENT OF LOW PRESSURES.

In the early period of development of the art a large number of different methods was suggested for measuring low pressures. These methods are described in the literature to which reference has been made previously.[44] Experience during the past decade has led to the elimination of most of these suggestions and for practical purposes there are relatively few types of manometers which have proved useful.

MERCURY MANOMETERS.

(1) The simplest type is the McLeod gauge, in which a given volume, V, of the gas, of which the pressure, P, is to be measured, is compressed in a capillary tubing of volume v and the resulting pressure, p, is then read directly as the length of a mercury column. For increased sensitivity, the ratio V/v must be made as large as possible, which necessitates the use of large volumes of mercury and capillaries of very small diameter. In this manner it is possible to make gauges sensitive to approximately 0.001×10^{-3} mm. of mercury.[45] Under these conditions, however, the action is very slow, and the mercury is apt to stick in the capillary. In ordinary practice, the McLeod gauge is used to read the pressure on the rough side of the fine pump and a sensitivity of 0.1×10^{-3} mm. is sufficient. Of course the greatest defect of this type of gauge is that it indicates only non condensable gases.

Various modifications of the gauge have been suggested. Thus A. H. Pfund [46] has increased the sensitivity by inserting a small filament in the capillary and using this as a resistance

[44] See references 1 to 5, footnote 1.
[45] W. Gaede, *Ann. Physik*, 41, 289 (1913).
[46] *Phys. Rev.*, 18, 78, July (1921).

gauge (see below) to measure the pressure, p, of the compressed gas.

K. C. D. Hickman [47] has described a form of mercury gauge recording pressures between 0.01 mm. and 5 mm. which may be found useful in certain types of low pressure investigations, but operates at too high a range of pressures for most purposes.

(2) *Resistance Gauge.*—M. Pirani [48] suggested a gauge which makes use of the fact that at low pressures the heat conductivity of gas is practically a linear function of the pressure. Pirani's gauge consisted of a bulb containing a tantalum wire heated electrically. The change in heat conductivity of the gas with pressure may be determined with such a gauge by one of the three methods:

(I) The filament is maintained at constant voltage, and the change in current measured as function of pressure.

(II) The resistance, and consequently the temperature, of the filament is kept constant and the change in total watts measured as function of pressure.

(III) At constant current the change in resistance is a measure of the pressure.

Pirani found that the last method gives the greatest sensitivity. In using the gauge a similar tube which has been well exhausted and sealed off at extremely low pressure is used as a compensator for variations in ambient air temperature.

C. F. Hale [49] developed an improved form of the Pirani gauge, which consisted of a fine platinum wire attached to the mount of a regular vacuum lamp. All contacts between filament and supports were welded and the resistance of the filament was measured by a Wheatstone bridge arrangement in which tube and compensator were inserted in two of the arms, while two other resistances, each, of approximately the same magnitude as that of the filament in the gauge, were inserted in the other two arms. For pressures ranging from 5×10^{-3} mm. downwards, the resistance was observed to vary approximately linearly with pressure. With this method

[47] *Jr. Opt. Soc. A.*, 18, 305 (1929).
[48] *Verh. d. Deutsch. Phys. Ges.*, 8, 24 (1906).
[49] *Trans. Am. Electrochem. Soc.*, 20, 243 (1911).

pressures as low as 10^{-5} mm. of Hg could be measured very satisfactorily.

N. R. Campbell [50] measures the change in voltage across the filament at constant resistance (Method II). If V_0 denotes the voltage at $p = 0$, and V the value at any pressure, p,

$$\frac{V^2 - V_0^2}{V_0^2} = k \cdot f(p),$$

where k is a constant for any given gauge and $f(p)$ has to be determined by a calibration.

More recently L. F. Stanley [51] has investigated the effect of various construction factors on the sensitivity of the instrument. Using a single wire loop of very fine platinum wire operated at very low temperature (below 100° C.), pressures within the range 2×10^{-5} mm. to 4×10^{-6} mm. could be measured very satisfactorily.

In this laboratory Messrs. H. C. Thompson and E. F. Hennelly have developed a simple form of direct reading gauge which has proved very convenient in practice. The measuring tube and compensator each consists of a glass tube 1 inch diameter and approximately 3 inches long in which four, or more, standard 25 watt, 115 volt tungsten filament coils are welded to supports, the total resistance being about 15 ohms at room temperature. The indicating tube, I, and compensator, C, are inserted in the two arms of a Wheatstone bridge as shown in Fig. 24, while the other two arms consist of two resistances R_1 and R_2 (about 14 ohms each) and a resistance R_3 (about 2 ohms) which can be adjusted to obtain zero current in the ammeter A. A dry cell battery supplies the constant source of potential.

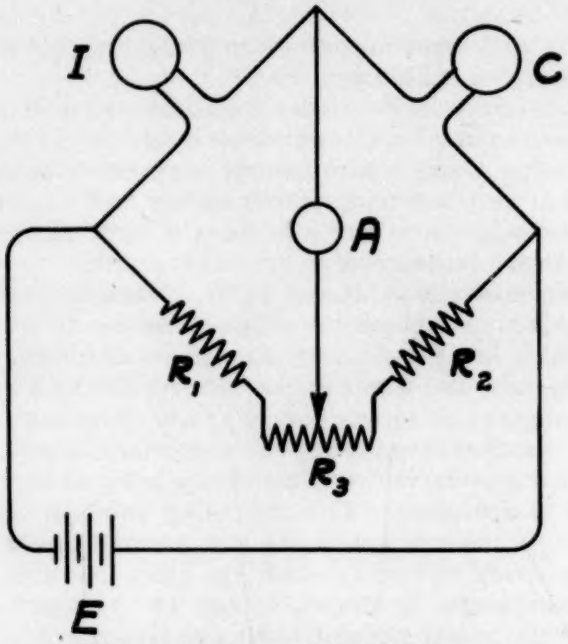
Figure 25 shows plots of current (in milliamps) versus pressure in microns (10^{-3} mm.) for a typical outfit. In order to prevent confusion three scales for pressure have been used, as shown. Curves A, B, and C refer to dry air at three different battery voltages, while curves D and E refer to hydrogen and argon respectively. It will be observed that for pressures below about 40×10^{-3} mm., the plots are linear and practically independent of battery voltage.

[50] *Proc. Phys. Soc.*, 33, 287 (1921).

[51] *Proc. Phys. Soc. London*, 41, 194 (1929).

By use of a sensitive milliammeter and care in construction of the tube and compensator, pressures as low as 10^{-6} mm. may be measured by this arrangement. Ordinarily, however, where it is desired to use a relatively cheap type of indicating instrument, the lower limit of sensitivity is between 10^{-5} and 10^{-4} mm.

FIG. 24.



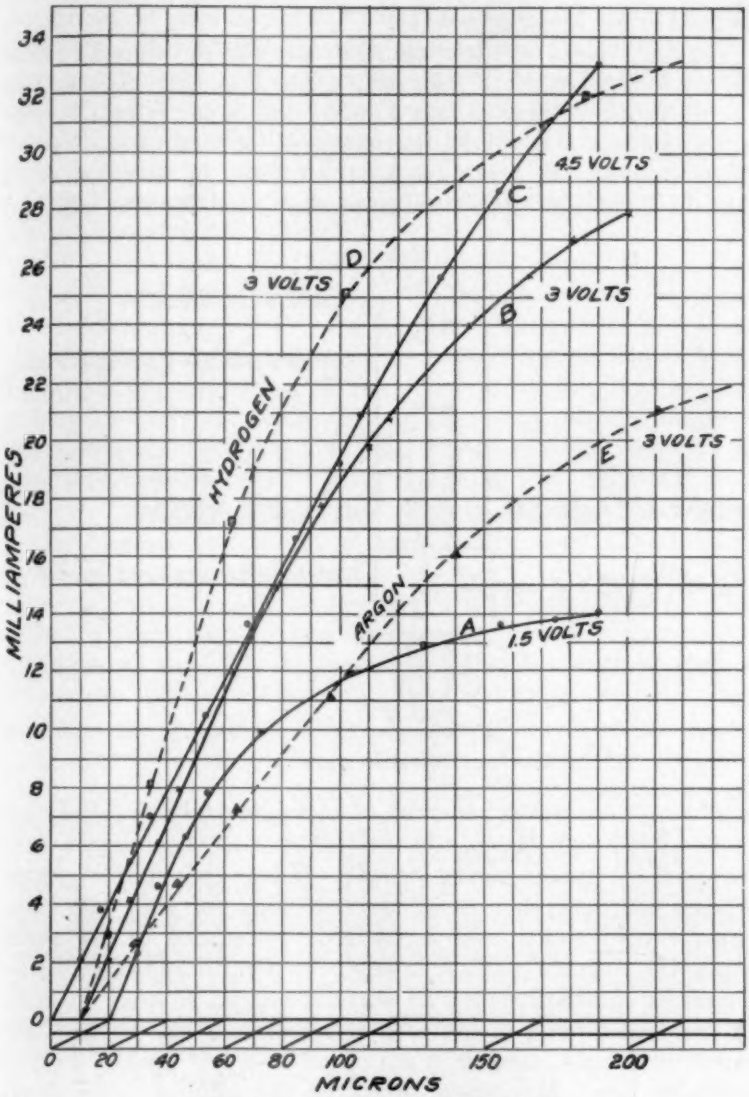
Wheatstone bridge connections for resistance gauge.

(3) *Thermocouple Gauge.*—Instead of measuring the change in resistance, the change in temperature of a heated wire may be measured by means of a thermocouple in contact with it. Rohn [52] observed that for a range between 7.5×10^{-2} mm. and 7.5×10^{-4} mm. the e.m.f. of the couple varied linearly with the logarithm of pressure, while the sensitivity decreased rapidly at lower pressures.

E. Rumpf [53] has described a gauge which consists of a platinum helix in the axis of which is mounted a thermocouple

[52] *Zeits. f. Elektrochem.*, 20, 539 (1914).
[53] *Zeits. f. tech. Phys.*, 5, 224 (1926).

FIG. 25.

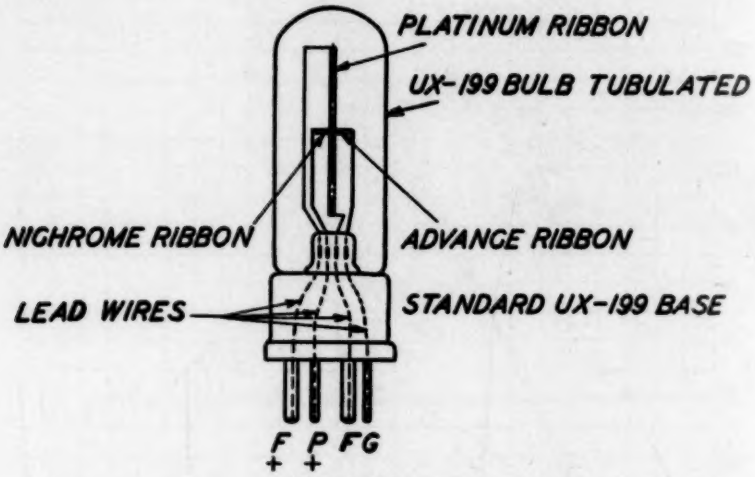


Current pressure relations for resistance gauge.

made of fine constantan and copper wire. Over the range 0.001 mm. to 3 mm. the e.m.f. varies approximately linearly with the logarithm of the pressure, while the gauge is very insensitive for lower pressures.

A gauge based on the same principle was developed in this laboratory by Dr. N. T. Gordon. (See Fig. 26.) It consists of a platinum iridium ribbon 0.00064 cm. × .0225 cm., to the center of which is welded a thermocouple of nichrome advance ribbon (.00125 cm. × .01 cm.), all mounted in on a four lead stem, in a tubular bulb similar to that used for the UX-199

FIG. 26.



Thermocouple gauge.

radiotron. A constant current of approximately 30 milliamps is passed through the platinum ribbon and the temperature measured by means of the couple. Three dry cells in series with a fixed resistance of about 110 ohms (of very low temperature coefficient) and a variable resistance of 40 ohms supply the current, which is read on a milliammeter, while a sensitive millivoltmeter of standard type is used to read the thermocouple e.m.f. The arrangement has to be calibrated, of course, against a standard McLeod gauge, for the particular gas. Hydrogen produces the largest deflections, while mercury vapor produces very small deflections for the same change of pressure.

(4) *Ionization Manometer.*—The most satisfactory method which has been found applicable to pressures below 0.1 micron is that involving a measurement of the ionization produced in the gas by a definite electron current. The electrons emitted from a tungsten or oxide coated filament, are accelerated by applying a positive potential varying between 100 and 250 volts to an adjacent electrode (the anode), and the positive ions resulting from collisions between electrons and gas molecules are collected by a third electrode which is maintained at a negative potential (10 to 50 volts) with respect to the cathode.

A gauge based on this principle was described by O. E. Buckley,[54] and the method was investigated more thoroughly by S. Dushman and C. G. Found.[55] The gauge used in this work is shown in Fig. 13. It consists of two helically wound tungsten spirals, of which the inner is used as cathode and the outer as anode, while the molybdenum cylinder surrounding these spirals is used as collector of positive ions. For a given electron current (1 to 20 m.a.) and constant anode voltage (100 to 250 volts) the ionization current is observed to be proportional to the pressure, while over a considerable range of electron currents (1 to 20 m.a.) the ionization varies linearly with the electron current. With this gauge the lower limit of pressure is determined by (*a*) the sensitivity of the instrument used for measuring positive ion current, and (*b*) electrical leakage between collector and filament. The latter is eliminated to a large extent by using the two stem construction shown in the figure. With a galvanometer indicating 10^{-7} amp. and 10 milliamp electron it is possible to read pressures as low as 10^{-8} mm. (10^{-5} micron).

While with this particular construction of gauge it was reported that the ionization current at constant electron current and given pressure is proportional to the total number of electrons per molecule, it has been found by Mr. N. B. Reynolds that this result was undoubtedly a fortuitous coincidence and is not valid for other designs of the gauge.[56]

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[54] *Proc. Nat. Acad. Sciences*, **2**, 683 (1916).

[55] *Phys. Rev.*, **17**, 7 (1921); **23**, 734 (1924).

[56] Complete discussion will be published in the near future.

For pressures of the order of 10^{-3} microns or higher, a regular type of three electrode vacuum tube may be used, and observations with gauges of this form reported by H. Simon [57] show the same proportionality of ionization current with electron current and pressure.

Of course it is essential before using this gauge to denude metal parts of gas by the usual methods. Since the oxide coated cathode is much less liable to injury by accidental inrush of air, it is often preferred for use in ionization gauges.

For very great sensitivity the positive ion current may be amplified by use of a push-pull amplifier circuit and a direct reading instrument of this type has been described by C. G. Found and N. B. Reynolds.[58]

Also the positive ion current may be used to charge up a condenser and a method of measuing the vacuum in radio tubes based on this principle has been described recently by M. D. Sarbey.[59]

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[57] *Zeits. f. Tech. Phys.*, 5, 221 (1924).

[58] *J. Opt. Soc. Am. and R.S.I.*, 13, 217 (1926).

[59] Electronics, April, 1931, p. 594.

A NOTE ON THE TIME REQUIRED TO SET UP CONDUCTION IN AN FG-17 THYRATRON AS DETERMINED BY A STUDY OF A LINEAR TIME AXIS CIRCUIT FOR AN OSCILLOGRAPH.

BY

W. B. NOTTINGHAM, E.E., Ph.D.

ABSTRACT.

BARTOL RESEARCH FOUNDATION.
Communication No. 54.

In connection with a study of small thyratrons recently published, certain results seemed to indicate that 1,000 micro-seconds were required to set up conduction, but an investigation using a cathode-ray oscillograph definitely shows that good conduction can be set up in 10 to 20 micro-seconds. A satisfactory explanation of the earlier result, not requiring a time lag, has been suggested by O. W. Livingston of the General Electric Company.

INTRODUCTION.

Cathode-ray oscillograph measurements using an FG-17 General Electric thyratron show conclusively that the time required to set up conduction in a thyratron is of the order of 10 to 20 micro-seconds even under unfavorable conditions, instead of 1,000 micro-seconds as previously suggested.[1] The earlier result came out as an incidental to a rather complete study of small thyratrons and depended upon the fact that the apparent maximum phase difference between the grid and plate potentials for which conduction could be set up in the thyratron was about 152° instead of 176° using 60 cycles A.C. The suggestion was made that this discrepancy of 24° between the observed and the calculated maximum phase difference could be explained by assuming that 1,000 micro-seconds were required to set up conduction, but in a personal communication, Mr. O. W. Livingston of the General Electric Company offered the alternative explanation that the condenser used in the "phase shifting" circuit charged up with grid current during the half cycle in which the plate potential was negative

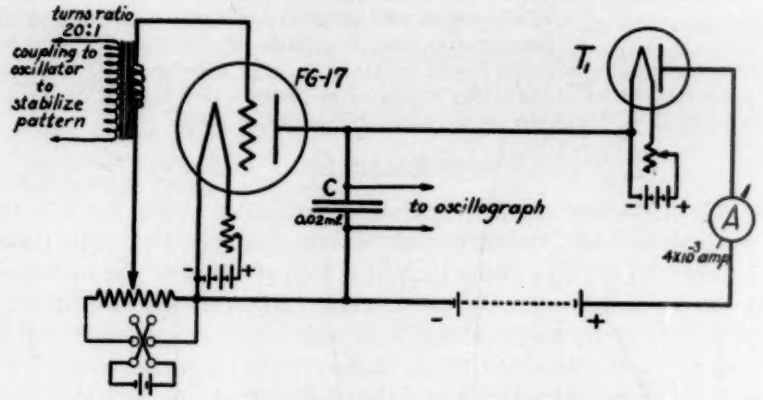
[1] W. B. Nottingham, JOURNAL OF FRANK. INST., 211, 271 (1931).

and the grid potential was positive with respect to the cathode. Although, this charge partly leaked off through the resistance of the "phase shifting" circuit, the grid was more negative than it should have been during the negative half of the grid potential cycle. Thus for a given *calculated* phase difference between the plate and grid potentials, the *effective* phase difference was probably greater by as much as the 24° observed.

NEW EXPERIMENTS USING A CATHODE-RAY OSCILLOGRAPH.

The thyratron circuit shown in Fig. 1 was set up to produce a linear time-axis for use with a cathode-ray oscillograph.

FIG. 1.

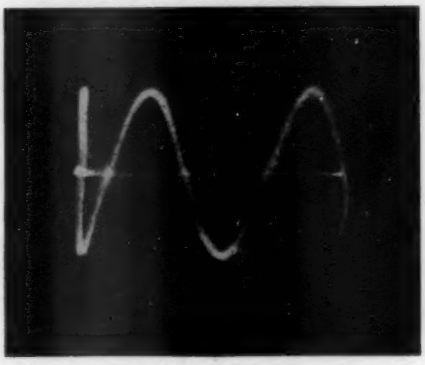


Thyratron circuit for linear time axis on cathode-ray oscillograph.

The operation of this circuit may be described briefly as follows: The electron current flowing across the vacuum tube T_1 is the saturation current and is therefore practically independent of the potential across T_1. This constant current charges the condenser C at a uniform rate and therefore causes its potential to increase linearly with the time until the potential is reached at which the thyratron is set to operate as determined by the grid potential. The thyratron then suddenly discharges the condenser, returning its potential to zero after which the cycle is repeated. Fig. 2 shows the pattern produced with a 10,000 cycle wave impressed on one

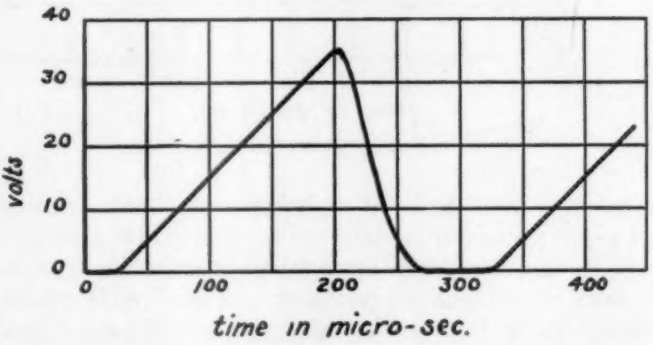
pair of plates while the time axis was operating at one-third that frequency. It is not only possible to study the wave form of the 10,000 cycle wave in this picture but it is also possible to obtain fairly accurate information concerning the

FIG. 2.



10,000 cycle wave with linear time-axis.

FIG. 3.



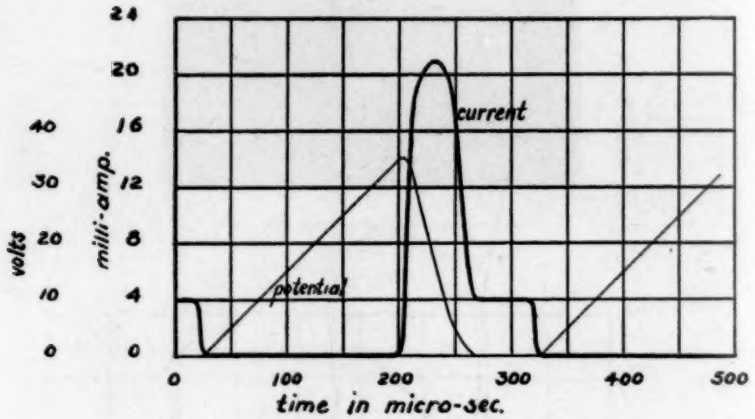
Thyratron (or condenser) potential as a function of the time.

current-potential relationship in the thyratron as a function of the time during the discharge.

The curve of Fig. 3, shows the potential across the plates of the condenser as a function of the time that was obtained from an analysis of the pattern shown in Fig. 2. Since the

current flowing into, or out of, a condenser is equal to the time rate of change in the potential multiplied by the capacity, it is possible to calculate the current flowing at any time from the slope of the potential curve at the time in question. The current flowing through the thyratron is obviously the algebraic sum of the condenser current and the constant thermionic current flowing through tube T_1. This current is shown by the heavy line of Fig. 4 while the potential is shown lightly for reference. It is evident from these curves, that the time required to set up good conduction in a thyratron is

FIG. 4.



Thyratron plate current as a function of the time.

considerably less than 30 micro-seconds even though the initial plate potential is only 35 volts and the grid potential exactly at the corresponding critical value. For quick operation, such conditions are probably the most unfavorable that are likely to be imposed in almost any thyratron problem. It is quite probable that under more favorable conditions good conduction could be set up in ten micro-seconds or less.

It is also of interest to note that the thyratron continues to be a fairly good conductor for about 75 micro-seconds after the plate potential has fallen below that at which appreciable further ionization can take place. The rated "deionization" time of 1,000 micro-seconds for this type of thyratron, is thus

seen to be very conservative in this particular application. The deionization time probably would have been much longer if the tube had been carrying its full load current of 0.5 amp. instead of a maximum of only 0.021 amp. as in this case.

In conclusion I wish to acknowledge my indebtedness to Mr. I. Melville Stein, Director of Research of Leeds & Northrup Company, for kindly loaning me the cathode-ray oscillograph and FG-17 thyratron used in this study.

The Preparation of Mirrors by Sputtering Metals on to Glass Surfaces. A. CHRISTOPHER G. BEACH. (*Jour. Sci. Instr.*, June, 1930.) Though the process of sputtering the metal of a cathode on to the cathode side of a sheet of glass interposed between the anode and the cathode in a vacuum tube through which an electric current passes has long been known and used, yet satisfactory results are not always attained. This paper describes in detail the method of getting excellent mirrors of silver and of nickel.

"The most usual source of trouble appears to be the use of too high an exhaust. The author's experience is that the cathode space should not touch the glass or the deposit is not so good and, if thick, may peel off." The glass surface to be coated rests face downwards about 2 cm. above the silver cathode. The vessel is exhausted by a "Hyvac" oil pump and no special gas is required. The current comes from the secondary of a transformer in which is included a Lodge valve tube. About 20 milliamperes pass through the sputtering tube, the potential difference between the electrodes being from 1000 to 2000 volts R.M.S.

Devices are used to remove the sputtered plate without jar or scratch, to exclude dust upon the admission of air, to facilitate the change of cathodes and to insure a clean surface for the deposit of the metal. "About 5 minutes with 10 M.A. gives a good deposit for interferometer plates," in the case of silver. Nickel requires a longer time.

G. F. S.

MODERN METHODS OF FIRE FIGHTING.*

BY

C. B. WHITE, M.E.

Chemist Engineer, American LaFrance & Foamite Corporation.

During the past fifty years many great changes have taken place in our means of transportation, in our methods of manufacture, in our systems of lighting, heating and communication. In fact our present machine-made civilization is virtually the product of the past fifty years. Our current popular literature is replate with reminiscences by such able writers as Mark Sullivan and Samuel Blythe, who very dramatically point out our accomplishments and our failures since "the turn of the century." But little has been written upon the effect of our altered civilization on our methods of fire fighting. It does not fall within the province of this article to list all of the changes which have taken place and which are taking place nor to philosophise upon the advantages and disadvantages of each. A very little retrospection will reveal to the thoughtful student the fact that our problems in the science of fire fighting have multiplied since the day when kerosene lamps lighted the homes of America.

As a single outstanding example, gasoline was a waste product in the year 1890. The distillation of crude oil was carried on largely to obtain the then valuable product kerosene. The gasoline was thrown out and burned up at the refinery. It was not only valueless; it was a nuisance. But all this has been changed by two revolutionary inventions—the incandescent lamp and the internal combustion motor. The former replaced the oil lamp and the latter transformed the waste material gasoline into one of our foremost necessities, so that the relation of the value of kerosene to gasoline today is almost the reverse of what it was forty years ago.

The rapid changes in our methods of doing almost everything coupled with a tremendous increase in the number and

* Presented at a meeting held Thursday, October 23, 1930.

variety of our inventions have introduced fire risks into our daily lives which were unheard of a generation or two ago.

Fifty years ago fires were largely confined to simple free burning materials in houses, barns, small factories, graneries and the like, and water in limited quantities could be counted upon to take care of practically all of these risks. Today even our fires in free burning materials are apt to be of much greater proportions than formerly, because of the centralization of industry into much larger units; but in addition we now have the oil and gasoline risks, the electrical hazard, the pyroxylin plastic risk and the fire hazard brought about by the introduction of scores of new solvents for all sorts of purposes.

Our ancient scientists had only a vague idea of the nature of fire. The alchemists classed fire as one of the four elements of which earth, air and water were the other three. In fact it was only a century and a half ago that Lavoisier, by a series of brilliant experiments, gave to the world the first inkling of what fire really is. It would be interesting (purely from a speculative standpoint) to determine just how far the science of fire fighting would have progressed if we were today still laboring with the phlogiston theory.

Modern science, however, defines fire as the combustion or rapid oxidation of a substance at, or above, its kindling point. If oxygen is absent combustion will not take place no matter what the temperature, and conversely a substance below its kindling point will not take fire even in the presence of abundant oxygen. This gives us valuable information regarding fire extinguishment—either cool the burning material below its kindling point or exclude the oxygen of the air from contact with the burning substance. All modern fire-fighting methods are based upon the application of one or the other of these two principles or upon a combination of both.

WATER.

Probably water will always be the most common fire extinguishing agent because of its abundance and wide distribution. But water is not particularly under discussion in this article because that which makes water a modern fire extinguishing medium is not the water itself but the means of its application.

From the days when water was delivered upon a fire by means of a bucket brigade or a crude hand pumper with its leather hose, we have made some mighty strides until today we are capable of delivering enormous volumes of water easily and rapidly. Single pumps with a capacity of 500, 750 and 1000 gallons per minute at pressures as high as 450 lbs. are standard equipment for the modern fire company. Many great inventions have made possible these high rates of delivery. The internal combustion engine besides increasing the road speed of fire apparatus and insuring its prompt arrival at the scene of the fire and immediate capacity discharge has stimulated the perfection of high speed pumps such as the rotary and the centrifugal types. Modern water works and high pressure mains in our larger cities are essential to the success of fire fighting on a large scale. Among the most important factors is one we frequently overlook, the utilization of rubber. Without rubber tires high speeds for motor vehicles would be out of the question; without rubber lined hose our high rates of water delivery would be futile because we would lack a proper flexible means of conducting the water any considerable distance.

Regardless of quantity or rate of application, however, there are fires which water will not extinguish; indeed there are certain types of fires which are greatly intensified and increased by water. We therefore must resort to the use of other agents for many present day fires and one of the purposes of this article is to classify these agents and assign to each its proper place in the scheme of modern fire protection.

CARBON TETRACHLORIDE.

Carbon tetrachloride CCl_4 is a clear, water-white liquid at ordinary temperatures. Its specific gravity at 21° C. is 1.5817. Its freezing point is −23.77° C. and its boiling point is 76.74° C.

Carbon tetrachloride is very volatile and its vapor, heavier than air, will not burn nor support combustion. These properties are made use of for fire extinguishing purposes by directing a stream of the liquid upon the fire which rapidly converts the liquid into vapor. Its chief value as a fire extinguishing medium lies in the smothering action of the

free vapor, although in certain cases the cooling action of the liquid itself is valuable. The quantity of vapor which may be produced from one pound of the liquid is about two and one-half cubic feet at room temperature and normal barometric pressure. It we assume an arbitrary figure of 600° F. for the temperature of the atmosphere immediately surrounding an ordinary fire the quantity of vapor which may be produced from a pound of the liquid will be five cubic feet.

Much has been written about the fumes generated in extinguishing fire with carbon tetrachloride. That undesirable fumes are formed under these conditions cannot be denied.[1] Fumes of CCl_4 itself have anæsthetic properties and in addition to these there are other fumes of an objectionable nature formed in small quantities by the decomposition of the CCl_4.

The consensus of opinion of the various investigators regarding the character of the gases formed and the precautions to be observed may be expressed briefly as follows:

1. Carbon tetrachloride extinguishers are usually small.
2. They are designed for incipient fires only.
3. Discomfort to the operator from fumes produced under special conditions is limited to cases where such devices are used in closely confined spaces where ventilation is poor and from which the operator cannot make a prompt exit.
4. These isolated cases of possible danger should not prevent the acceptance of carbon tetrachloride extinguishers for the protection of those risks for which they are preëminently fitted.

The devices used in the application of CCl_4 range in capacity from 1 quart to 2½ or 3 gallons. There are a few types for special purposes larger than this but they are rare. In fact the most common size is the 1 quart. The method usually employed for ejecting the liquid from its container is hand pumping although the sizes of 1 gallon or larger are equipped with cylinders containing air under pressure, which is capable of forcing the liquid out of its container through a suitable nozzle. The normal range of stream for the hand

[1] JOURNAL OF THE FRANKLIN INSTITUTE, October, 1920, pages 543–565. *N. F. P. A. Quarterly*, January, 1921, pages 221–243.

CHARACTERISTICS OF FIRE EXTINGUISHERS

TYPE			TETRACHLORIDE	SODA-ACID	FOAM	CARBON DIOXIDE
CHEMICALS EMPLOYED			Carbon Tetrachloride with important components for depressing freezing point, avoiding corrosion, etc.	Bicarbonate of Soda Sulphuric Acid	Aluminum Sulphate—Bicarbonate of Soda with Foaming Agent	Commercially pure liquid carbon dioxide free from moisture, etc.
METHOD OF OPERATING			PUMP	INVERT	INVERT	OPEN VALVE
METHOD BY WHICH PRESSURE IS CREATED			PUMPING ACTION	CHEMICAL REACTION	CHEMICAL REACTION	PRESSURE STORED IN CYLINDER
EFFECTIVE RANGE OF STREAM			20 FEET OR MORE under full pump pressure	30 TO 40 FEET	30 TO 40 FEET	6 TO 8 FEET under full pressure
RATED LIQUID CAPACITY OF MOST COMMON SIZE			¼ GALLON	2½ GALLONS	2½ GALLONS	15 LBS.
QUANTITY OF PRINCIPAL EXTINGUISHING AGENT PRODUCED			Quantity variable — depends upon amount of liquid which comes in contact with heat of fire.	2½ GALLONS	20 GALLONS	Quantity variable—about 135 cu. ft. of gas at normal temperature
NATURE OF PRINCIPAL EXTINGUISHING AGENT			FREE GAS produced when liquid is vaporized by heat of fire.	LIQUID soda solution	FIREFOAM a mass of bubbles filled with carbon-dioxide gas	FREE GAS produced when liquid is released from cylinder
PRINCIPAL EXTINGUISHING EFFECT			BLANKETING	COOLING	BLANKETING	BLANKETING
IT IS RECOGNIZED AS ADAPTED FOR USE ON	Class A Fires	Wood, Textiles, Rubbish, Etc.	NO Other types are better adapted for Class "A" fires. This type good only under most favorable conditions because of:—small size, difficulty of confining gas at seat of fire; force, range, and duration of stream not automatically assured; operator cannot devote entire attention to directing stream on fire; must be used with caution in small rooms.	YES for use in places *not* involving oils, greases, etc., in any way. Must be kept in heated cabinet when installed in places subject to freezing temperatures.	YES BEST AVAILABLE for use in all places involving Class "A" fires because of desirable characteristics not possessed by any other extinguishing agent (fireproofing effect; smaller wetting effect, etc.) Must be kept in heated cabinet when installed in places subject to freezing temperatures.	NO Other types are better adapted for Class "A" fires. This type good only under most favorable conditions because of difficulty of confining gas at seat of fire, short range of stream, not useful on overhead fires.
	Class B Fires	Oils, Greases, Etc.	YES but foam type is better adapted for Class "B" fires. This type good only under most favorable conditions because of:— small size; difficulty of confining gas at seat of fire; force, range and duration of stream not automatically assured; must be used with caution in small rooms.	NO because it has practically no blanketing effect.	YES BEST AVAILABLE for use in all places involving Class "B" fires because of characteristics not possessed by any other type.	YES but foam type is better adapted for Class "B" fires. This type handicapped by short range of stream. Difficulty of confining gas at seat of fire except under most favorable conditions.
	Class C Fires	Electrical Machinery	YES Satisfactory where fires have not spread beyond extinguishing capacity of extinguisher and especially in places where current is not likely to be turned off, because stream is a non-conductor.	NO except on low voltage when used with caution, or where current is likely to be turned off. Stream is a conductor but a poor one.	Best available where fires have spread beyond the extinguishing capacity of tetrachloride extinguishers and where current is turned off or is of low voltage. The stream is a conductor, but a poor one.	YES BEST AVAILABLE where Class "C" fires have not spread beyond extinguishing capacity—stream is a non-conductor, has no wetting, no solvent effect and leaves no residue.
	*Class D Fires	Pleasure Automobiles, Commercial Trucks, Etc.	YES BEST AVAILABLE for Class "D" fires because it has a blanketing effect and is not subject to freezing. On account of its size it can be used on pleasure automobiles.	NO has practically no blanketing effect, not splash-proof, subject to freezing. Not suitable for pleasure automobiles because of size.	NO Unless of special splash-proof construction. Must not be exposed to freezing temperature. Not suitable for pleasure automobiles because of size.	YES because it has a blanketing effect and is not subject to freezing. On account of its size, it can not be used for pleasure automobiles.
UNDERWRITERS' RATING			B2—C2—D1	A1	A1-B1	B1-C1

*The letter "D" is for convenience, no letter having been assigned to this class by Underwriters' Laboratories

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[1] J
N. F.

pump devices is in the neighborhood of 20 ft. under full pump pressure.

Mention of the capacities of the most common tetrachloride devices serves to bring out the fact that they are usually of rather small calibre. Therefore in any discussion of the merits of this fluid as a fire extinguishing material we must limit the *size* of the fire in mind to the size of the extinguishers commonly available.

For Class A fires (wood, textiles, paper, rubbish) carbon tetrachloride is not recommended but under favorable circumstances will give a good account of itself. It is not recommended because other types are better adapted to this class of fire and because of the difficulty of confining the free gas at the seat of the fire; in the case of the hand pump devices the force, range and duration of the stream are not automatically assured; the fluid must be used with caution in small rooms or other confined spaces.

For Class B fires (grease, oil, gasoline, kerosene) tetrachloride is acceptable for small, incipient fires where the depth of the inflammable material is superficial. In cases where the fuel is present in considerable depth, liquid tetrachloride passes through the flame without volatilizing sufficiently to produce a non-combustion-supporting atmosphere and since the liquid is miscible with practically all the materials in Class B it promptly distributes itself through the fuel. In the case of gasoline it is necessary to add a volume of tetrachloride equal to half the volume of the fuel before the mixture will cease to burn. For instance, a mixture of 20 per cent. carbon tetrachloride with 80 per cent. gasoline will burn. A mixture of 30 per cent. carbon tetrachloride with 70 per cent. gasoline will just burn. A mixture of 40 per cent. carbon tetrachloride with 60 per cent. gasoline will flash and go out.

For Class C fires (electrical machinery) carbon tetrachloride is recommended because it is a non-conductor of electricity and may be used with safety around live electrical machinery and switchboards. Here again the question of size of apparatus is a factor, and where the fire has spread beyond the extinguishing capacity of the extinguisher other materials are to be preferred.

The value of tetrachloride for strictly electrical fires may may be summed up by the statement that for such fires as fall within the limited capacities of available carbon tetrachloride extinguishers CCl_4 is as good an extinguishing medium as we possess.

For Class D fires (trucks, buses and pleasure motor vehicles) carbon tetrachloride extinguishers are the best available. In this class the majority of fires occur under the hood, where the fire-smothering vapor of CCl_4 may be banked in a very confined space while the operator remains in the open free from objectionable fumes. The devices are compact, comparatively light, rapidly brought into operation and not subject to freezing.

For certain classes of motor vehicles such as the oil tank truck, other types of extinguishers are sometimes preferred, but in the main the Class D risk is best protected by CCl_4.

SODA AND ACID.

The type known as Soda-Acid is the oldest form of chemical fire extinguisher in use today, and it has proved its value for the extinguishment of fires in free burning materials beyond any question. Extinguishers of the Soda-Acid type depend for their operation upon the reaction between an acid and a solution of a carbonate. In the most common form the acid is sulphuric and the carbonate is sodium bicarbonate. The reaction may be expressed by the following equation:

$$2NaHCO_3 + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O + 2CO_2$$

The two solutions are normally kept separate until the extinguisher is brought into play when they are allowed to come together. The reaction evolves a sufficient volume of CO_2 to eject the liquid contents of the extinguisher through a suitable hose and nozzle.

Properly designed charges for Soda-Acid Extinguishers are provided with an excess of sodium bicarbonate to guard against an occasional "flash" or "slug" of the acid, which might escape through the nozzle during operation and cause damage and injury. In fact the common Soda-Acid charge contains twice as much bicarbonate as will satisfy all of the acid present so that the equation really becomes

$$4NaHCO_3 + H_2SO_4 \rightarrow 2NaHCO_3 + Na_2SO_4 + 2H_2O + 2CO_2$$

and the danger of expelling free acid with the stream is minimized.

Opinion among fire-fighting engineers is somewhat divided regarding the extinguishing value of the Soda-Acid stream as compared with an equal quantity of water similarly applied, but the majority hold to the belief that the difference if any is slight. The value of Soda-Acid equipment lies in the fact that it may be brought into play instantly, that it is self-actuating and that the stream range is such that a fire may be fought from a distance of thirty to forty feet.

Soda-Acid Extinguishers generate a relatively large volume of CO_2 gas. For instance, the average $2\frac{1}{2}$ gallon size will produce $3\frac{1}{2}$ cubic feet of CO_2 or something more than ten times the volume of the liquid capacity. At first glance this quantity of fire smothering gas would appear to be a very substantial addition to the fire extinguishing properties of this type. As a matter of fact, however, the CO_2 generated by the Soda-Acid Extinguisher is practically valueless for fire smothering purposes except back of a partition or in some similar, small, dead-air space where draughts and the heat of the fire will not dissipate the CO_2. Therefore, the fire extinguishing effect is limited for all practical purposes to cooling.

Soda-Acid machines are manufactured in a variety of sizes the most common of which are the $1\frac{1}{4}$ gallon, $2\frac{1}{2}$ gallon, 20 gallon and 40 gallon portable machines and the 40 gallon stationary engine for mounting on motor fire apparatus.

For Class A fires within the limits of available sizes Soda-Acid devices are recommended.

For Class B fires Soda-Acid Extinguishers and Engines are not recommended, because of the absence of smothering effect and because the force of the stream frequently causes spattering of the burning liquid fuel.

For Class C fires Soda-Acid streams are not recommended, except where the electric current is known to be turned off, because of the wetting effect and because they are conductors of electricity to some extent.

For Class D fires Soda-Acid machines are not recommended partly for the reasons given under Class B fires and also because of the bulk and weight of the available sizes and because the liquids are subject to freezing in cold weather.

FOAM.

In the discussion of Soda-Acid the volume of CO_2 evolved was mentioned as being relatively large when compared with the volume of the solutions which produce it. In its free and unconfined state, however, the volume of CO_2 produced by these devices is practically valueless for fire smothering purposes. Many years ago it was recognized that if this valuable gas could somehow be trapped so that it could be applied locally and be held for a sufficiently long time in contact with a fire without being carried away by draughts it could be put to work as a fire smothering medium. It was known that the action of an acid upon a sodium bicarbonate solution is attended by numerous bubbles of CO_2 which produce a temporary froth, and it was recognized that if these bubbles could be made strong and tough enough the problem of entrapping the CO_2 would be solved.

The reaction between aluminum sulphate solution and a solution of sodium bicarbonate will produce a fairly durable bubble structure because the bubble film is reinforced with insoluble, colloidal aluminum hydrate. The equation expressing the reaction is as follows:

$$6NaHCO_3 + Al_2(SO_4)_3 .18H_2O \rightarrow 6CO_2 + 3Na_2SO_4 + 2Al(OH)_3 + 18H_2O$$

But the bubbles so formed, even though more rugged, migrate rapidly and the friction attending their passage through a short hose and nozzle quickly breaks down the bubble structure allowing the CO_2 to escape.

If to one or both of the two solutions a suitable protective colloid be added to keep the bubbles of CO_2 in a finely dispersed form the reaction will result in a stabilized foam that will withstand considerable abuse without breaking down. As a rule the colloidal stabilizer is added only to the bicarbonate solution.

A great many colloidal substances may be made to serve in the capacity of foam stabilizer but the practical application of most of them to fire fighting is limited. In order for the foam method to become commercially possible the stabilizer must be inexpensive and easily available in practically unlimited quantities. It must disperse in water with a minimum

of sediment, be free from a tendency to decompose and be capable of producing maximum strength and durability of bubble wall. Egg albumin, glue and other substances of animal origin are capable of producing a very fine bubble structure, but besides being expensive they decompose readily and lose the characteristics which make them valuable as fire-foam producers. Foam stabilizers, therefore, are taken preferably from the vegetable kingdom. Among the most successful of these may be mentioned secondary extract of licorice root, saponin and soap bark.

The oldest form in which the foam method of fire fighting came into general use is the foam system for the protection of oil storage tanks. After this the portable extinguishers were developed together with a variety of automatically operated foam contrivances. Of comparatively recent origin are the dry powder foam devices. Each of these divisions of the foam method must be treated separately.

The Foam System.—Using 3 per cent. foam stabilizer with 8 per cent. sodium bicarbonate and 89 per cent. water as one solution (called "B") and a 13 per cent. solution of aluminum sulphate, $Al_2(SO_4)_3 . 18H_2O$, as the other (called "A"), means are provided for the protection of oil tank farms and refineries. The two solutions are kept in separate tanks from which they may be pumped simultaneously, when needed, through twin lines of piping to appropriate mixing chambers installed on the oil storage tanks. Here they meet to form foam which issues from the mouth of the mixing chamber and flows over the surface of the burning oil. Hose stations are provided at suitable points along the course of the twin solution lines to make the system as flexible as possible and to provide protection for various hazards outside the oil tanks All hose lines are also twin—a line for each solution—and the two solutions are siamesed together at a common nozzle, thus insuring, as in the case of the mixing chamber, that the foam produced will be subjected to a minimum of loss by friction.

An average foam installation in the oil fields would be represented by 100,000 gallons of each solution stored in appropriate tanks and a twin duplex horizontal steam pump capable of delivering 500 gallons of each solution per minute

to the mixing chambers and hose stations. There are smaller systems than this in use in the oil industry and there are also much larger ones. By opening the appropriate valves and starting the pump the foam producing solutions may be directed to any one of the oil tanks in the farm or to any hose station.

There are ten million gallons of these foam system solutions periodically examined by the author and it is estimated that fully as many more are in use. In addition to these land systems there are a great many marine systems installed in steamships, such as the Majestic and Leviathan, for protection against the oil hazard in their boiler rooms. These systems, of course, are much smaller than those used on land.

Portable Foam Devices.—Turning now to the portable foam extinguishers we find the "B" solution very similar in strength to that used in the Foam System, viz., 8 per cent. bicarbonate (or a little better) plus the stabilizer of course. The "A" solution in portables is somewhat more concentrated, usually running 50 per cent. of the theoretical $Al_2(SO_4)_3 \cdot 18H_2O$ or close to four times the concentration found in system practice. Naturally, a correspondingly smaller quantity of this stronger "A" solution is required to preserve the theoretical balance of the "A" and "B" salts demanded by the chemical equation.

This is as it should be for any saving in bulk and weight results in greater carrying ease. The decrease in water content also results in a stiffer quality of foam. This is highly desirable, because the idea of portability carries with it the idea of limited capacity, which means that the operator must use the foam at his disposal in an economical manner. The stiffer foam allows him to do this because it has a tendency to stay where it falls. Portability also implies the presence of a human hand to direct the stream to the spot where it will do the most good and to be less dependent upon the fluidity of the foam to spread itself over a burning surface as in the case of system practice.

Automatic Foam Machines.—Devices for automatic foam protection vary somewhat widely in type but all depend for their actuation upon some device which is influenced by heat, such as a fusible alloy which melts at a prescribed temperature or a bulb containing air which expands upon being heated

and which in turn operates a series of levers or diaphragms to release the two solutions into a common chamber for the production of foam. In some cases pipe lines lead the foam to suitable nozzles situated near the surface of the hazard where the foam is ejected by virtue of its own expansive force. For smaller risks the automatic machines are hung directly over the hazards and the foam is allowed merely to drop by gravity on to the fire. Automatic protection finds its greatest usefulness in the protection of dip tanks for enamelling automobile parts, in oil quenching tanks, etc.

Dry Powder Foam Machines.—It will be noted that between the 40 gallon engine, which is the largest portable foam device, and the 100,000 gallon system there is a tremendous gap. Some apparatus was demanded to take care of the fire hazards which are beyond the capacity of the portable device but too small for the fixed system—something which might be used by fire fighters for stubborn fires which would not yield to water—something flexible, easily transported, not bulky.

This most recent development for the application of foam is the dry powder foam machine. Stripped of technicalities it may be described as a device for the continuous production and delivery of foam capable of extinguishing fires. The idea comprises flowing water from a source of supply toward a point of discharge, effecting a substantially continuous introduction of suitable foam producing ingredients in powder form into the water stream from an exterior supply. The proportions of the foam producing chemicals introduced into the water are substantially constant with respect to each other and to the rate of water supply so that when the reagents are conducted together in the presence of a foam stabilizer they will react to produce a stable gas filled foam capable of floating on oil.

The essential features of the apparatus are shown in Fig. 1. Water under pressure is supplied at the water inlet and is forced through a restriction or orifice at high velocity. As the water is expelled from the orifice as a solid jet it tends to create a vacuum. Powder poured into the hopper will be drawn into the water stream by the vacuum.

It is obvious that by the use of such a machine only 15 per cent. of the total weight of foam-producing materials (the dry chemicals) need be transported to the scene of the fire and the other 85 per cent. (the water) would be pumped to the machine from the nearest source. The dry chemicals are provided in powder form. The powder may be compounded of the correct proportions of aluminum sulphate, sodium bicarbonate and dry stabilizer as a single homogeneous mixture, in which case it is fed into the machine and the foam is produced in the discharge hose leading to the nozzle; or two separate powders may be used, one consisting of aluminum sulphate and the other of a mixture of sodium bicarbonate and dry stabilizer, each powder in this case being

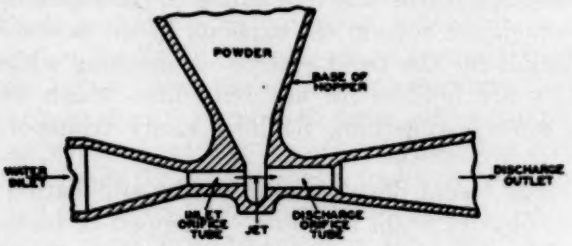

FIG. 1.

fed into a separate machine. In this latter type of dry powder foam machine the two streams are either brought together at once into a common hose line or two separate lines, one for each solution, are carried out to siamese together at a remote common point to produce the foam.

In the single powder type (or in the two powder type in which the two streams are brought together immediately into into a common line) the length of single discharge line can be longer than is practicable in the fixed solution system, without impairing the quality of the foam, because the foam is being made in transit, so to speak, solution and reaction occurring in the hose. Discharge lines of 100 to 150 ft. lengths are permitted without a destructive friction action on the foam.

In the two powder type in which two separate discharge lines are used it is obvious that these lines may be extended a considerable distance because the foam is not produced until the solutions are brought together at the point where the foam

is needed and consequently the foam is not broken down in transit. The author prefers the single powder type with the single machine equipped with hose and nozzle for portable practice and the two powder type equipped with twin lines leading to a remote mixing point for fixed system practice.

For Class A fires foam is highly recommended, because it clings with great tenacity to both horizontal and vertical surfaces and besides its smothering action it has a decided cooling effect. In this connection it is interesting to note that although the foam is composed of 90 per cent. CO_2 by volume it contains by weight more than 85 per cent. water. Foam also contains aluminum hydrate which possesses the property of rendering cellulose somewhat fire resistive.[2] This fact is thought to contribute to the fire extinguishing value of foam on free burning fires by inhibiting the tendency of fire to reflash over surfaces on which the flame has once been extinguished.

For Class B fires foam is the best available. Heavier than air yet lighter than the lightest inflammable liquid, foam stands preëminent. Its value is especially marked in oil fires of large dimensions.

For Class C fires foam is recommended with reservations. The reason for the reservations is that foam is a conductor of electricity, though a poor one, and if the voltage is high and the current cannot be turned off the equipment there may be danger to the operator. It also leaves a considerable deposit to be cleaned off electrical machinery after a fire. Frequently the Class C fire resolves itself into the question "When is an electrical fire not an electrical fire?" For example, the oil switch or oil-cooled transformer fire may very properly call for foam.

For Class D fires foam type extinguishers are not recommended, except where climatic conditions are such that the solutions will not be subject to freezing temperature or where they can be protected, and where the bulkiness of the foam devices is not objectionable, for example on oil tank trucks and motor buses. When used for motor vehicles specially constructed extinguishers are used to prevent the solutions slopping together due to the motion of the vehicle.

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[2] *The Textile World*, Oct. 29, 1921. *Scientific American*, February, 1921.

CARBON DIOXIDE.

Carbon dioxide at ordinary temperature and pressure is a gas, one and one-half times as heavy as air. It is readily reduced to a liquid by applying suitable pressure if the temperature is below 88° F., the critical temperature of CO_2. This property is made use of in placing the material on the market. It appears in heavy steel cylinders, the commonest size holding 50 lbs. The pressure within these containers is the vapor pressure of carbon dioxide and this varies with the temperature. At ordinary room temperature the pressure will be between 800 and 900 lbs. per square inch. One pound of liquid CO_2 when converted to gas at room temperature and normal atmospheric pressure will occupy approximately 9 cubic feet. Thus a single cylinder with a capacity of 1.36 cubic feet containing 50 lbs. of CO_2 is capable of producing 450 cubic feet of the gas when released into the atmosphere.

The knowledge that free carbon dioxide gas will extinguish fire is old and the art of using it for that purpose is also old. The only reason why the CO_2 method has but lately found a general and widespread use is that only during recent years has there been a real need for it.

In order to be used most effectively for fire-fighting CO_2 must of course be discharged rapidly and in adequate volume. The common commercial cylinder of liquefied CO_2 is not well adapted for rapid discharge because it is designed only for carbonating water and beverages, which calls for a very low rate of discharge. Any attempt to use such common type of cylinder for fire extinguishing is likely to be unsatisfactory for this reason and may result in the freezing of the liquid CO_2 before it escapes. Cylinders with larger outlets and used either inverted or provided with syphon tubes are therefore employed.

As in the case of foam there are two general classifications of Co_2 devices, the fixed system and the portable extinguishers. These are so different that they will be treated separately.

The Fixed CO_2 System.—The difficulty cited above has long since been solved by the use of ordinary puncture type valves, which permit sudden and rapid exit of the gas, and by providing outlet orifices sufficiently small in proportion to the

diameter of the piping to minimize the drop in pressure between the cylinder and the nozzle. Preserving a proper ratio between nozzle orifice and pipe diameter will prevent or minimize expansion *within* the system and confine it to the *outside* of the nozzle so that freezing and snow-making occur only beyond the point of discharge. For discharges lasting for long periods the nozzle should be of such a shape that its coldness will not cause freezing of the liquid CO_2 or water therein and cause stoppage.

Where fire may be expected to occur in an enclosed space in which a fire extinguishing atmosphere of CO_2 may be established and maintained for a given period of time the enclosure may be provided with a suitable fixed system of CO_2 protection. It is merely necessary to dilute the air in the enclosed space with enough CO_2 so that the resulting atmosphere will not support combustion and to maintain this condition until the fire is out. A very good example of such a risk is the enclosed electric generator. Figure 2 shows schematically the general arrangement of closed generator protection.

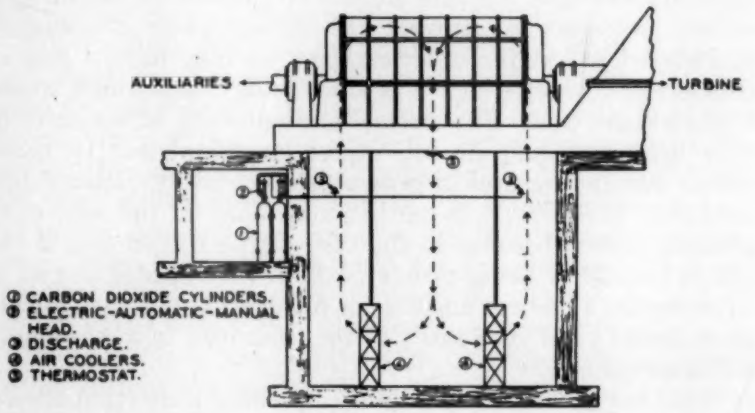

FIG. 2.

If fire should occur in the generator the rise in temperature would cause the thermostat to set off an initial discharge of one or more 50 lb. CO_2 cylinders, the number having been predetermined by a knowledge of the static air content. At

the same time the generator would automatically be cut out and the armature would start to slow down; but from 1800 R.P.M., for instance, to complete rest takes about thirty minutes. During this time the initial discharge of gas would have to be augmented by the discharge of additional cylinders at intervals to maintain the concentration of CO_2 between proper limits. The number and timing of the additional cylinders, which would be set off by an electrically operated time delay unit, would be determined by the rate of leakage of gas from the generator housing.

In much the same way cargo spaces on shipboard may be flooded, as well as fur storage vaults and similar risks. It is necessary to know the cubic capacity of the space to be protected and the amount of leakage likely to occur. An atmosphere of 25 per cent. carbon dioxide is taken as the basis for the design of space protection apparatus. This figure has been determined experimentally to be sufficient to extinguish fires in most common combustible materials. The time necessary for complete extinguishment depends entirely upon the character of the burning material. At one extreme we may have, for example, burning alcohol or gasoline for which it is merely necessary to provide the extinguishing atmosphere momentarily. At the other extreme we may have a bale of cotton the core of which is a smoldering mass which would require many hours in a normal extinguishing atmosphere of CO_2 before extinguishment would be complete. In other words, smoldering fires in general are not easily extinguished by CO_2. However, it is hard to generalize on the subject of glowing carbon because in the case of the cotton fire, if the fibers, instead of being closely packed, were spread out so as to present a sufficient surface for heat radiation, the glowing spots would yield very easily to the treatment in a reasonably still atmosphere.

It is hardly necessary to add that space protection should be laid out and installed by competent engineers. Each installation presents its own problems and each should be separately engineered.

Portable CO_2 Extinguishers.—For fires in the open, portable CO_2 devices are available in various sizes from cylinders containing as little as 5 lbs. up to 50 lbs. The smaller ones

are designed to be lifted around by hand while the larger units are mounted on wheels.

It is obvious that although CO_2 gas is heavier than air it cannot be depended upon to fall through flame and heated vapors and strike at the seat of the fire. The natural tendency of the free gas is to expand under the influence of heat and to rise with the draught created by the fire. Hence in the design of portable CO_2 apparatus it is desirable to discharge the gas as much as possible in the form of a column with the least coning or divergence and at a proper velocity. Any pipe of proper dimension is suitable for this result. Added to this is the fact that freshly expanded CO_2 has a very low temperature (110° below 0° F.), but although this undoubtedly has some effect it is now believed to play only a minor part in the extinguishment of most fires.

Portable CO_2 equipment possesses certain advantages over all other types of portable fire apparatus. It is quick in action, especially good for certain hazards, it has no wetting effect, it is "non-freeze," a non-conductor of electricity, it is "three dimensional" in its action, requires little maintenance and the contents are good until used.

On the other hand, the range and duration of discharge are both short, the devices are heavy, the cylinders must be sent away for recharge and they are awkward to handle in narrow places. In addition, this type of extinguisher should be handled by an operator experienced in the use of the device and who understands the specific fire which confronts him. For a few seconds the operator, on account of the short range, must take a little more heat punishment than the unskilled fire fighter would stand up to. There are no halfway measures with CO_2. Either the operator "gets" his fire entirely or he fails completely. The CO_2 blanket is so rapidly dissipated that if a speck of flame remains the entire fire area may reflash and the work of extinguishment has to be done all over again.

For Class A fires portable CO_2 devices are not recommended, except for fires in burning insulation resulting from electrical fires in switch-boards and similar hazards. These fires are regularly extinguished by means of portable carbon dioxide extinguishers.

For Class B fires CO_2 is recommended where the conditions are favorable, viz., where the oil or gasoline fire is in an enclosed space which can confine the gas at the seat of the fire; or for fires in the open which are protected by adequate portable CO_2 extinguishers operated by experienced operators.

For Class C fires CO_2 is the best available where total flooding may be used, for example, in the closed electric generator. Also for certain electrical hazards in the open where it is inadvisable to use carbon tetrachloride.

For Class D fires CO_2 is not ordinarily recommended because of the size and weight of the portable devices. Certain special cases such as oil tank trucks are sometimes protected with portable CO_2 devices but in these special risks the question of the weight and bulkiness of the apparatus is not a serious factor.

SPECIAL TYPES OF FIRES.

Among the inflammable liquids are several which require special mention. *Carbon bisulphide* is a particularly inflammable liquid and for this reason one would naturally suppose that foam would be the best available material for extinguishing fires in it. Foam is capable of doing the work fairly well, but because of the high specific gravity of carbon bisulphide water may be used. The much lighter water will float on the surface of the CS_2 and *smother* the fire. However, it is necessary to apply the water gently to prevent splashing.

Alcohol.—Fires in alcohol and acetone are not successfully fought with foam. Foam is miscible with alcohol and the latter breaks down the bubble structure of the foam to a very marked degree. Fire in these liquids may be extinguished by diluting with water to the point where they will not burn, if there is sufficient space in the storage tanks, or the fire may be extinguished with CO_2.

Pyroxylin Plastics.—Fires in pyroxylin plastics may be divided into two classes and treated separately.

1. Motion picture film, X-ray film, etc., *in small quantities* such as one or two rolls of motion picture film may be protected by foam, but it is to be remembered that no hand extinguisher can be considered as 100 per cent. effective from the standpoint of *extinguishing* even small film fires. The

real measure of relative value lies in subduing the flames and protecting adjacent material not on fire.

For film fires of large proportions water is the most efficient extinguishing agent. Since the Cleveland Clinic disaster of May, 1929, much study has been given to this subject. With the pyroxylin at a temperature above its decomposition point it breaks down, producing deadly gases which are often more far reaching in their effect than the fire itself. The necessity, therefore, is for an extinguishing agent which will cool the mass below the temperature at which it will decompose. Water in great abundance is therefore recommended.

2. Pyroxylin Lacquer.—Here the fire is less a pyroxylin risk than a solvent risk and water is valueless. Foam or CO_2 are recommended.

Tar, Pitch, etc.—Certain substances like tar, pitch, asphalt, paraffin wax are solid at ordinary temperatures but become liquid if heated and finally ignite if heated high enough. Obviously, to cool such a material below its ignition point is all that is necessary to extinguish such a fire. Water is not recommended for this purpose because the ignition points of most of these materials are above the boiling point of water which evolves steam in contact with the fuel and causes boiling over. If foam is used with care the surface of the burning material may be cooled and the fire extinguished. Foam in too great abundance, however, is liable to cause boilover. CO_2 is valuable for these fires.

Metal Dust.—Finely divided metal like aluminum dust frequently ignites. Water and foam merely aggravate the fire causing it to burn with greater violence. CO_2 is not effective. The most useful material for such a fire is dry sand or some other material which will absorb heat without adding moisture.

Calcium carbide in the presence of moisture liberates acetylene which is highly inflammable. Obviously water as a fire extinguishing medium must be avoided and although foam has successfully extinguished so-called carbide fires it requires very skillful application. Either carbon tetrachloride or CO_2 is indicated for extinguishing carbide fires.

Planes Obtain Weather Data Once Secured by Kites. (*Popular Mechanics*, June 1931.) For nearly thirty years, the weather bureau has used kites to explore the upper air, obtaining much valuable data from the instruments carried aloft in this manner. The wide extension of aviation, however, is likely to cause early abandonment of these kites because they are considered a hazard to flying. In some cases, the kites are sent aloft by several miles of powerful but invisible wire. If an airplane came in contact with such wires, serious damage might result. Instead of kites, the government now is planning to secure observations in the free air by means of daily airplane flights, and has already invited bids for such a service in several localities. It is anticipated that the cost will not be any greater than the kite flying, and the planes can go aloft on many days when kites cannot be sent up. Kite stations cost from $10,000 to $12,000 a year to maintain. R.

BREAKDOWN VOLTAGE AS A FUNCTION OF ELECTRODE AREA AND DIELECTRIC HOMOGENEITY.

BY

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If a number of samples of insulation, all apparently similar as regards composition, thickness and area, are subjected to breakdown tests made under identical test conditions, they will not all fail at the same value of voltage but, due to inherent inhomogeneities in the composition of individual samples, they will show variations in breakdown voltage. These breakdown voltages will form a distribution which has been found to follow approximately the normal probability law.[1] The more inhomogeneous the insulation, the greater will be the variation from sample to sample, and the more widely will these voltages be scattered about the mean value. This suggests that the breakdown voltage of large areas of insulation, containing many such samples, should be a function of area and homogeneity as well as thickness. The function may be deduced as follows.

Assume a number of tests to have been made as described, all on samples of unit area. The voltage distribution of the results may be represented by the normal law,

$$F = N\left[\frac{1}{2} - \frac{1}{\sqrt{2\pi}}\int_0^k e^{-k^2/2}dk\right], \qquad (1)$$

where $k = (1 - E/\bar{E})/S$,

$\bar{E}$ = Mean Breakdown Voltage of Unit Samples,

S = Coefficient of Variation of the Distribution, $= s/\bar{E}$,

s = Root-Mean-Square Deviation, $= \sqrt{\Sigma d^2/N}$,

d = Deviation of Individual Results from the Mean,

N = Total Number of Samples Tested,

[1] "Precision Measurement of Puncture Voltage," Bush and Moon, *Trans. A. I. E. E.*, 1927, Vol. XLVI, p. 1025.

F = Number of Samples Failing between Voltage Limits Zero and E.

Since the distribution is symmetrical, one-half the results will lie between the limits $E = 0$ and $E = \bar{E}$. The mean breakdown voltage, then corresponds to an average of one-half failure per sample. If larger sized systems be considered, each containing N units of insulation, the mean breakdown voltage of such systems will correspond to the value of E implicit in equation (1) when F is set equal to one-half. Doing this, there results

$$\frac{1}{2} = N\left[\frac{1}{2} - \frac{1}{\sqrt{2\pi}}\int_0^k e^{-k^2/2}dk\right], \tag{2}$$

and solving for E,

$$E = \bar{E}\left[1 - S\cdot\text{erf}^{-1}\left(\frac{N-1}{2N}\right)\right], \tag{3}$$

in which the function, $\frac{1}{\sqrt{2\pi}}\int_0^k e^{-k^2/2}dk$, has been represented by the operator "erf (k)". Then, "$\text{erf}^{-1}(k)$" represents the inverse operation. In short, "$\text{erf}^{-1}\,[(N-1)/2N]$" means, "the quantity whose error function is $[(N-1)/2N]$." Its value may be obtained conveniently from error function tables, just as values of sin and $\sin^{-1}$ are obtained from tables of sines.

The final equation (3), then, gives the mean breakdown voltage E of any system as a function of the coefficient of variation S, the mean breakdown voltage $\bar{E}$ of the units comprising the system, and the number N of such parallel-connected units in the system. The parameter S is a constant which may be used to specify the inhomogeneity of the insulation (or the variability of the units comprising the system). It is determined experimentally from breakdown tests made on the unit samples.

The final equation (3) is entirely general. It may be applied to all kinds of insulation, . . . either in the form of continuous areas, as in cables, or in the form of discrete units, as in overhead transmission lines. In the former case N represents length of cable measured in terms of some standard

test length as a unit; in the latter case, N represents the number of units of line insulation under voltage stress, . . . the number of strings of insulators along an overhead line for example. In the case of thin sheets of insulation, N may be taken to represent electrode area, in which case the equation gives breakdown voltage as a function of electrode area and insulation variability. The equation shows quantitatively the importance of securing uniformity in the manufacture of insulation. It should, therefore, find many practical applications in the field of Electrical Engineering.

Eight Quakes in April Bring Year's Total to Forty-Four. (*Science News Letter*, May 9, 1931.) With a series of eight earthquakes, culminating in the destructive Caucasus shocks at the end of the month, April has maintained the high earthquake record of the first quarter of 1931, and has followed the example of the preceding month, which ended with the wrecking of Managua on March 31. The total of major earthquakes for the year, up to May 2, now stands at 44.

The earthquakes of April occurred on the 4, 6, 15, 19, 20, 22, 24 and 27. The last date was that of the destructive quake in the Caucasus region; though the telegraphic reports of it did not come out from Moscow until the twenty-ninth. None of the other seven quakes, fortunately, caused any notable damage to life or property. One, a very mild one, rattled dishes and doors and cracked a few ceilings in the Hudson and Mohawk valleys in New York State. This was on the twentieth. The second and third quakes of the month, on the sixth and fifteenth respectively, were midocean earthquakes on opposite sides of the earth. The first agitated the Pacific ocean bottom almost on the equator, in the neighborhood of the Caroline islands, and the second occurred in the Atlantic, a little west of the Azores.

The first earthquake in May was reported on Saturday, the second. Its epicenter was located in interior Venezuela.

COMMITTEE ON SCIENCE AND THE ARTS.

ABSTRACTS OF REPORTS.

RUTHS' STEAM ACCUMULATOR.

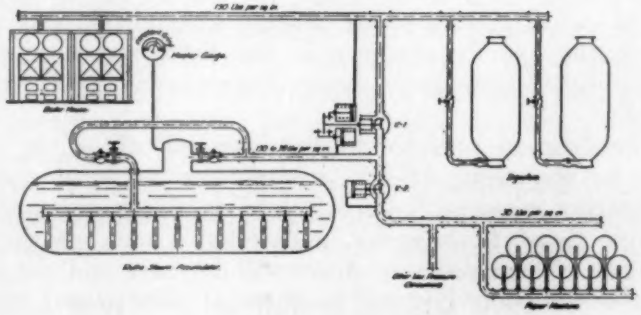
HALL OF THE INSTITUTE,
PHILADELPHIA, October 3, 1928.

No. 2875.

The Franklin Institute of the State of Pennsylvania, acting through its Committee on Science and the Arts, investigating the Ruths' Steam Accumulator invented by Doctor Johannes Ruths, of Djursholm, Sweden, reports as follows:

The purpose of this device is to provide extra power in steam plants to meet a sudden demand or overload. The fundamental idea is to provide a container, separate from the boiler, partly filled with water, into which steam at a high pressure can be delivered and from which it can be withdrawn when the demands in a plant are beyond the capacity of the boilers.

PLATE I



To show how this idea can be applied, a diagram of a simple system as used in a pulp and paper mill is shown in Plate I. In this installation the accumulator is connected

to the piping system leading from the boiler house by means of a single steam line in which there is a regulating valve *V*–1. This is a compound valve controlled by the pressure in the boiler house main, in which it maintains a constant pressure, 150 lb. per square inch, for example, as shown in the Plate.

Leading from the boiler steam line to the accumulator is a pipe that is used to admit steam to the accumulator for storage, and to take it out of the accumulator for use. The feed pipe, bringing in steam at 150 lb. pressure has in it a one-way valve, shown on the left, connected to the distributing pipes through which the steam is delivered into the water. Steam accumulating in the dome on the top of the accumulator passes out through the one-way valve on the right to feed into the lower branch of the steam line that carries steam to the paper machines at a pressure of 30 lb. per square inch. Valve *V*–2 in this line is a pressure reducing valve by means of which the pressure is reduced to the required amount and kept constant.

The digesters on the right are fed directly from the main steam line from the boiler.

If at any time the amount of steam being generated is the same as that being used, that at 30 lb. pressure used in the paper machines will pass directly through valves *V*–1 and *V*–2 and none will pass into the accumulator or be drawn from it. If, however, more steam is required in the digesters, the resulting drop in pressure will cause regulating valve *V*–1 to cut down the steam flowing through it, thus maintaining the 150 lb. pressure in the main steam pipe and diminishing the amount of steam that passes into the accumulator line.

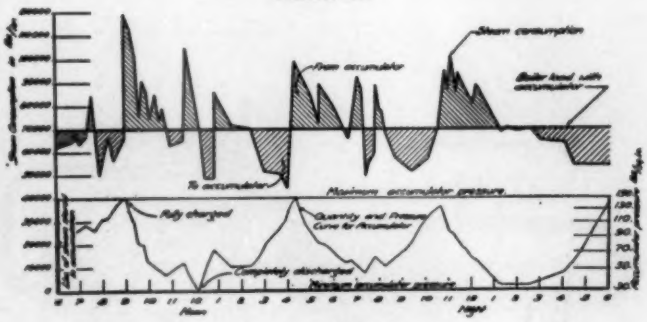
The drop in pressure in this line will allow the check valve in the dome of the accumulator to open and the evaporating steam will be delivered to the paper machines through *V*–2. If, however, a digester is cut out the consumption of high pressure steam will decrease and the excess steam in the boiler line will be automatically passed into the accumulator line through *V*–1. This will supply more steam to this line than is being used in the paper machines through valve *V*–2 and the pressure will increase enough to open the check valve in the charging line admitting the surplus steam

into the water of the accumulator where it will increase the temperature of the water until the evaporated steam pressure equals that generated in the boiler house when it is again ready to supply the demands of a peak load.

The foregoing action is dependent on a pressure of 150 lb. per square inch being constantly maintained at the boiler house.

Plate II shows a set of curves recording the performance of a Ruths' Accumulator installation for a twenty-four hour run.

PLATE II



The horizontal line indicates the boiler load with accumulator, the shaded portion below this line shows the steam pressure delivered to the accumulator when the load demand is below 70,000 lb. per hour, while the shaded portion above the line shows the steam pressure delivered by the accumulator when the demand is above that amount. The lower curve shows the condition of the accumulator both as to the accumulated pressure in pounds per square inch and the pounds of steam stored.

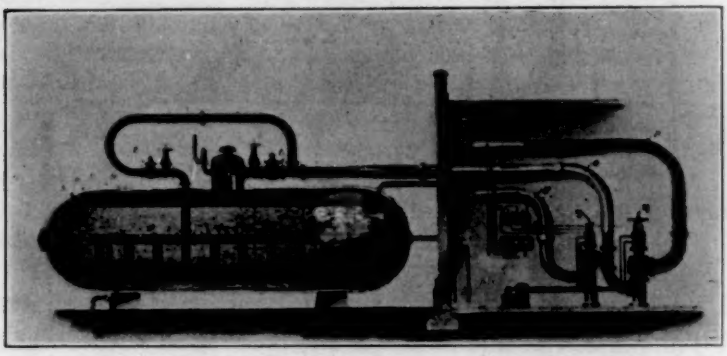
Plate III is made from a cross-section drawing through a Ruths' Steam Accumulator and Steam Switch Board showing the actual construction of the plant shown diagrammatically in Plate I.

Steam line *N* in the switch board is connected directly with the boilers and all steam in excess of that used in the high pressure parts of the plant passes through valve V_1 to the accumulator line *O*. This valve maintains a constant high pressure in line *N* while the reducing valve *V*–2 main-

tains a constant pressure in the low pressure line *P* from which steam is supplied to low pressure users.

Any excess of steam passing through *V*–1 that does not pass through *V*–2 will be carried through pipe *O* and check valve *E* to distribution pipe *F* and steam nozzles *G* into the water of the accumulator in which it will be stored by raising the temperature of the water. Whenever the steam demand in the low pressure line is greater than the amount passing through valve *V*–1, the pressure in line *O* will drop, check

PLATE III



valve *E* will close and the reduced pressure in the steam space above the water will cause rapid evaporation to take place and the steam so formed will pass out through check valve 1 into pipe *O* and through valve *V*–2 thus keeping up the pressure in pipe *P*.

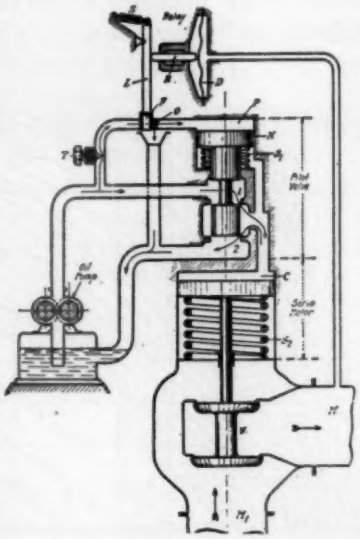
A number of United States Patents have been granted on this apparatus and of these No. 1,585,790 granted on May 25, 1926 to Johannes Karl Ruths of Djursholm, Sweden, on an application filed June 20, 1919, appears to include more fully than any of the others the principles of the device already described. Among the objects of the invention are mentioned: to maintain a constant generator pressure automatically in a plant having a variation between steam generation and steam consumption; to relieve a plant of variations due to unequal application of heat to a generator due to differences in fuel and irregularities in firing; and to

relieve a plant of variations of steam consumption by users connected ahead of an accumulator.

Since modern boilers are becoming increasingly able to carry a widely fluctuating load, a very important use of the accumulator will probably be in balancing the demand for process steam exhausted from steam prime movers with the mechanical load on the prime mover.

The patent specifications describe and illustrate by drawings different forms of valves that can be used between the boiler main, the accumulator and the working machines. Modifications have been made in the development of the device and Plate IV shows a section through a pressure

PLATE IV



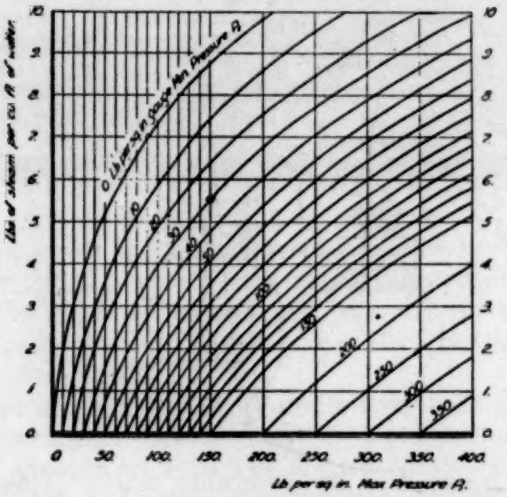
regulating valve and its governing relay. This particular form of combined valve and relay has been developed to meet the requirements for high sensitivity and accuracy of action combined with reliability in operation.

The valve *V* is of the balanced type and is operated by an oil servomotor which is itself operated by oil pressure under the control of a pilot valve and relay. This plate illustrates the action of a reducing valve for the maintenance of a constant pressure in main *M*. A decrease in the pressure in

M will be transferred to the relay and cause its steel diaphragm *D* to move to the right. Rod *R* follows the diaphragm and spring *S* causes the lever *L* to turn on its fulcrum. By this movement the lower forked end *F* of the lever covers a greater area of the openings *O* on both sides of the pipe. The decrease in the size of the openings *O* increases the pressure in *P* forcing pilot-valve *N* down against the spring S_1. This opens port *1* and allows oil at a constant pressure to pass into chamber *C* above the servomotor piston forcing it down against the pressure of spring S_2 and opening valve *V* wider.

This pressure, acting on the under side of piston *N* pushes it upward, closing ports *1* and *2* and bringing the piston of the servomotor to rest in the desired position. If there is an increase in the pressure in *M*, the reverse action will follow and valve *V* will close.

PLATE VII



The advantage that can be derived by the use of a steam accumulator combined with a boiler may be seen by a consideration of Plate VII which gives a set of curves showing the steam storage capacity of hot water under pressure. In the case of the steam boiler having 150 lb. constant pressure, as assumed in this report, and the 30 lb. pressure required in the paper machines, the Plate shows that 5.5

pounds of steam are obtained from each cubic foot of water. For this especial drop of 120 lb. in pressure the storage capacity of the accumulator is many times that of a boiler with the same capacity for water. The size of the accumulator will depend on the amount of steam desired. If, for example, 30,000 pounds of steam are required in the plant described and 90 per cent. of the volume of the accumulator is occupied by water, the volume of the accumulator will be

$$\frac{30{,}000}{5.5 \times 0.9} = 6060 \text{ cubic feet.}$$

The Ruths' Steam Accumulator has been extensively used abroad, more than three hundred installations having been made. Several installations have also been made in the United States and Canada.

The Institute's Committee corresponded with a number of users and the reports received have been uniformly in favor of this method of steam storage.

In consideration of the excellence of design of the control equipment and the adaptation of sound principles to the successful production of large steam storage apparatus, THE FRANKLIN INSTITUTE awards its JOHN PRICE WETHERILL MEDAL to DOCTOR JOHANNES RUTHS, of Djursholm, Sweden.

Occurrence of Two Oxyhemoglobins in the Blood. Hitherto, the red blood cell has been considered to contain but one chromoprotein, hemoglobin, which absorbs oxygen in the lungs, becomes oxyhemoglobin, and transports the oxygen to the tissues. ALEXANDER GEIGER (*Proc. Royal Soc.* 1931, *B 107*, 368–380) has isolated two different oxyhemoglobins from the blood of the ox, sheep, ass, dog, and man. They were separated by electrodialysis and cataphoresis, and differ with respect to their oxygen dissociation curves.

J. S. H.

Organic Acids of Spinach, Broccoli, and Lettuce. E. K. NELSON AND H. H. MOTTERN (*Jour. Am. Chem. Soc.*, 1931, *53*, 1909–1912) have determined the organic acids present in these vegetables. Spinach contains 0.31 per cent. oxalic acid also citric acid and a small quantity of malic acid. The leaves and the buds of broccoli have materially the same composition and nutritive value; the predominating organic acid is citric acid; laevo malic acid and small amounts of oxalic acid and succinic acids are also present; the citric and malic acids are in the ratio 3 : 2. Lettuce contains 0.011 per cent. oxalic acid, approximately 0.065 per cent. laevo malic acid, and approximately 0.048 per cent. citric acid.

J. S. H.

Molecular Weight of Casein. D. C. CARPENTER (*Jour. Am. Chem. Soc.*, 1931, *53*, 1812–1826) finds that the most probable value for the molecular weight of casein, the phosphoprotein of milk, is 98,000. This conclusion is based on results obtained with the ultracentrifuge, and on quantitative determinations of the sulphur, phosphorus, cystine, tryptophane, tyrosine, and histidine content of the casein.

J. S. H.

Influence of Menhaden Oil on Lard. J. B. BROWN (*Jour. Biol. Chem.*, 1931, *90*, 133–139) fed pigs a ration containing approximately 14 per cent. of menhaden oil. The lard obtained from these pigs contained 2.7 per cent. of highly unsaturated acids, which had about the same molecular weight but a lower iodine number than the acids isolated in a similar manner from the original oil.

J. S. H.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

QUARTERLY MEETING OF FEDERAL FIRE COUNCIL.

The regular quarterly meeting of the Federal Fire Council was held at the Department of Commerce, April 10. Dr. George K. Burgess, chairman presided. Twenty-two representatives from departments and establishments were in attendance. Dr. Burgess called attention to the fact that this was near the first anniversary of the organization of the group on April 3, 1930. He reviewed briefly some of the results of the year's activities. This included preliminary surveys of the institutions under the Board of Public Welfare of the District of Columbia which resulted in allowance for substantial items for fire protection in the appropriations available for the coming fiscal year. Following a request from the Committee on Rules of the Senate an inspection for fire hazard of the Senate Wing of the Capitol building and the Senate Office Building was undertaken, and as recommended in a preliminary report on immediately needed protection measures, $100,000 was made available at the last session of Congress. Other projects completed include a report on the National Training School for Boys located on Bladensburg Road in the District of Columbia. He indicated that the benefits from these surveys are measured only in part by the appropriations made available and that the improvements in housekeeping and greater attention paid to matters concerned with fire prevention and protection are possibly of equal or greater value.

A. G. Thomas, Chairman of the Fire Hazards Committee reported on surveys in progress in the Smithsonian Institution and the Capitol group of buildings. During the period since the last meeting a fire protection survey of the Atlanta Penitentiary had been made by the field engineering department of the National Fire Protection Association which was reported at this meeting. This was a comprehensive inquiry

* Communicated by the Director.

into the structural, occupancy, and equipment conditions having a bearing on the fire hazard and the results were embodied in a 100 page report.

W. W. Dean, chairman of the apparatus and appliance committee reported on work of the groups of his committee on various installations involving automatic sprinklers, automatic fire detecting equipment, fire doors, and other structural changes proposed in connection with the different surveys.

Dr. H. C. Dickinson reported on the preliminary work being done by the committee on inspection and interdepartmental coöperation which has consisted in obtaining data on value of government property subject to fire loss and the measures taken for its protection.

H. W. Gardner of the U. S. Veterans Administration outlined the fire prevention and protection activities of this establishment. A number of instruction sheets, brief manuals and report forms are provided the various stations, and check-ups on fire prevention and protection conditions are made at least once a year by an outside agency or an officer not attached to the station. The Veterans' Bureau has at present 54 field activities located throughout the country. While the newer stations have fire resistive buildings of the most approved types, there are many buildings taken over that are at best only of semi-fire-resistive construction, necessitating the strictest care in connection with fire prevention. The loss from fire in Veterans' Bureau hospitals has been almost negligible during the past ten years.

Capt. R. C. Montgomery, chief of the protection division of the Office of Public Buildings and Public Parks of the National Capitol described the fire prevention and protection activities in connection with the public buildings under the supervision of this office. This includes a wide range of buildings in Washington, ranging from temporary frame structures to monumental buildings such as the Lincoln Memorial and Washington Monument. Buildings acquired for demolition on sites of new buildings are also under the care of this office, about 50 buildings being at present in this class. The buildings causing this office the most concern from the standpoint of fire hazard are the large temporary buildings constructed in 1917 and 1918 to house war activities. While a

few, such as the Navy and Munitions buildings are of fire resistive construction, most of them are wood frame buildings These buildings have at times housed as many as 30,000 employees. No fire loss of any consequence had occurred in connection with the use of these buildings until last year when Temporary Building No. 4, occupied by the Federal Trade Commission and bureaus of the Department of Labor, was burned with loss estimated at $164,000. For the preceding seven year period some 400 fires have occurred in the buildings under the control of this office, most of them extinguished before any damage of consequence had occurred. The total loss from these fires is given as about $1,600 or about $4.00 per fire. In only seven cases was the District Fire Department called and in only three of these was it required to go into action.

This record was established only as the consequence of thorough-going and sustained fire prevention work aided by drills of employees in the proper use of fire extinguishing equipment and maintenance of the latter in good condition. As an example, each of the 2,650 hand fire extinguishers located in these buildings is recharged every year. Smoking is prohibited in the temporary buildings, and the effect of this is shown in the less frequent occurrence of fires in these buildings than in the fire resistive buildings where smoking is allowed and where generally the fire prevention measures applied are less stringent. The office anticipates, with satistion, the demolition of the last of the temporary war buildings and the substitution for them of types of buildings such as the new Internal Revenue Building and the Commerce Building that have incorporated in them, from standpoint of both structure and equipment, some of the features that are most effective in preventing the origin and spread of fire.

TWENTY-FOURTH NATIONAL CONFERENCE ON WEIGHTS AND MEASURES.

The Twenty-fourth National Conference on Weights and Measures will be held at the Bureau of Standards, June 2 to 5, inclusive. Weights and measures representatives will be present from a majority of the States, and representatives of

manufacturers of weighing and measuring apparatus and of numerous railroads and industries will also be present. A new feature planned for the conference this year is an exhibit of recent developments in connection with weighing scales. Scale manufacturers have been invited to place on exhibition devices which have been developed or put into use during the past twelve months. There is also expected to be an exhibit of person-weighing scales, not confined to recent developments, in connection with the consideration of a tentative code of specifications and tolerances for person weighers.

One half-day session will be devoted to the discussion of bottles used for dispensing lubricating oils at filling stations. such bottles are now in extensive use, but some are not in compliance with the code of specifications for lubricating-oil bottles which has been adopted by the conference. In the case of some of these bottles, it is the contention that they are used merely as containers, the bottle being sealed and comprising a "package," the actual measuring being done by the machine which fills the bottles. There is some sentiment to the effect that all bottles should conform to the requirements adopted by the conference for bottles used as measures; it is expected that the conference will reach a definite decision upon this point.

Certain matters having to do with the maintenance of commercial weighing and measuring devices have formerly been included in the conference codes of specifications. It is now to be proposed that these be separated from the technical requirements which may properly be classed as "specifications," and be grouped under a code of "regulations," which will be recommended for adoption by the States.

Representatives of the United States Department of Agriculture will discuss the marking of packages of food under the net weight amendment to the Food and Drugs Act, and a proposed consolidation of Federal standard container legislation. A representative of the Weights and Measures Inspection Service of Canada will discuss the system of weights and measures administration in force in that Dominion. New equipments for testing large-capacity scales, recently put into service by State and local departments of weights and measures, will be described and illustrated. A representative

of the Post Office Department will discuss the supervision of Post Office scales. Several papers will be presented by members of the staff of the Bureau of Standards.

Numerous other papers relating to some phase of weights and measures control will likewise be presented to the conference. Advance indications are to the effect that the conference sessions will be well attended.

EFFECT OF SMALL VARIATIONS IN PITCH UPON THE INDUCTANCE OF A STANDARD SOLENOID.

In the May number of the *Bureau of Standards Journal of Research* a method is described by which the variations in pitch of a single layer solenoid may be compared with those of the precision lathe-screw used to wind it. Assuming that the pitch of the latter is constant, but not known with precision, it is shown how the precision measurements of the length of the windings may be combined with the former measurements to obtain the variation in pitch of the windings relative to an ideal helix whose beginning and end points coincide with the actual one. A mathematical formula for computing the correction δL to the inductance due to this variation in pitch is then developed. This formula requires the graphical integration of a certain function times the deformation, and practical methods of evaluating it are described. Application is made to observations on two standard solenoids, and shows that the correction δL to the inductance L may amount to four or five parts in a hundred thousand, even on the most carefully constructed solenoids. In absolute measurements the correction is therefore by no means to be neglected, although it seems hitherto not to have been taken into account in determinations of the ohm.

HEIGHT OF KENNELLY-HEAVISIDE LAYER.

The bureau is conducting a series of studies on the height of the Kennelly-Heaviside layer. The height of this layer above the earth's surface varies from 40 to 400 miles, and is the principal factor determining the distance of transmission of radio waves on different high frequencies. The study of this

height is the most powerful means available of studying the vagaries of radio transmission. Considerable work has been done on the measurement of layer heights by the echo (or reflection or group retardation) method. With this method a very brief and sharp radio-frequency pulse (of a few ten-thousandths second duration) is transmitted thirty times per second from a transmitter to a receiver about 10 miles away. If the waves travel only along the ground a single pulse is obtained at the receiving station each thirtieth of a second. If, however, a part of the waves travel upward and the Kennelly-Heaviside layer reflects or refracts them back to the receiver, two or more pulses are received instead of one. The sky-wave pulses are retarded behind the ground-wave pulse because they have travelled a longer path. The amount of this retardation is usually from a few ten-thousandths of a second to a few thousandths of a second. At the receiving station the pulses are photographed on the moving film of an oscillograph, and the time retardation of the delayed pulses thus measured. From the time retardation and the known velocity of propagation in free space the effective height of the reflecting or refracting layer is determined.

Beginning June 1, the bureau will issue a weekly bulletin giving KHL heights. This will be broadcast by radio telegraphy from the Arlington naval radio station, as a part of the Ursigram bulletins of cosmic data compiled by Science Service and distributed by that organization in mimeographed form to interested scientists.

Apparatus for this work has not been highly developed previously. For satisfactory work the transmitter should send out a strong pulse lasting a ten-thousandth of a second, and the receiving equipment including the oscillograph should be capable of receiving this without distortion or widening of the pulse. The bureau has been developing such apparatus. This includes a transmitter with suitable pulse-making equipment, special receiving sets, and amplifiers. A continuous automatic recorder of Kennelly-Heaviside layer heights has also been devised, and will permit the issuing of daily bulletins of the height if found desirable. It is expected that papers describing the apparatus will be published during the present year. When such papers are published announcements will be made in these columns.

ALTITUDE LABORATORY TESTS OF AIRCRAFT ENGINES.

Fourteen years ago the Bureau of Standards designed and built the world's first laboratory for determining the performance of aircraft engines under the precise conditions of low temperature and rarified air which exist at high altitudes. The so-called altitude chamber where the engine is mounted for test is a reinforced concrete box capable of withstanding an external pressure of a ton per square foot. Powerful vacuum pumps evacuate the chamber and take away the exhaust gases. A shaft carried through the wall of the chamber connects the engine with a dynamometer for controlling the load and measuring the power developed. Connections are also made through the chamber walls for supplying metered quantities of air, fuel, oil and water to the engine; for adjusting throttle and spark advance; and for measuring the temperatures and pressures in and about the engine. Thus all operating conditions are controlled and all measurements made without entering the altitude chamber during a test.

As reported at the Fifth National Technical Aeronautic Meeting of the American Society of Mechanical Engineers in Baltimore on May 12, altitude laboratory tests have been made for the Army or the Navy on many representative aircraft engines, both American and foreign. In addition to tests of particular engines under standard conditions, much general information has been obtained as to the influence of engine design and operating conditions on performance. The effects of temperature and pressure on engine power and the gain obtainable by supercharging are illustrated by results of tests made in the altitude laboratory on a modern 12-cylinder water-cooled aircraft engine.

There is needed at the present time a corresponding altitude laboratory for the accurate testing of large air-cooled aircraft engines under the conditions encountered in flight. Such a laboratory will differ from the present installation chiefly in having provision within the evacuated engine chamber for the circulation of low-density air at the high velocity required for efficient engine cooling. The Navy has already made tests of certain air-cooled engines under approximate

altitude conditions by controlling the pressure of the air supplied to the carburetor and connecting a suction line to the engine exhaust manifold.

THERMAL PROPERTIES OF ALCOHOL AND BENZENE.

A series of experiments at the bureau to determine two important thermal properties of certain familiar liquids has just been completed. Methyl or wood alcohol, ethyl or grain alcohol, and benzene have been the subjects of this investigation. It is now possible to say, with an error of less than one-tenth of one per cent., how much energy in the form of heat is required to raise the temperature of a known mass of any one of these liquids from one value to another. The quantity of heat energy required to evaporate known masses of these liquids has also been measured with approximately the same precision, and such values are now available as the most important result of the present work.

Values of these properties which have been measured by previous investigators are discordant, and some of them must necessarily be very inaccurate. This recent work reduces the magnitude of the uncertainties which previously existed. The results here obtained find numerous applications, not only in science, but also in industrial processes involving production and purification of the substances.

The work will be reported in full in the May number of the *Bureau of Standards Journal of Research.*

CONTROLLING DIMENSIONAL CHANGES IN ELECTROTYPES.

Electrotyping is an accurate method of reproducing the designs of printing plates, and is extensively used for high-grade printing, including half-tones. Slight changes in the dimensions of a plate used for one-color printing are usually not objectionable. In four color printing, however, the four plates must register accurately in order to reproduce the originals. Difficulty is sometimes experienced by electrotypers in making plates for color printing that have exactly the same corresponding dimensions.

In an investigation at the bureau, made in coöperation with the International Association of Electrotypers, plates were made under practical shop conditions and were then measured carefully to determine what changes in dimension were produced in each step of the process. The conditions used in each operation were then varied and these plates were measured in order to determine how closely each operation must be controlled to secure a high degree of uniformity, for example to within a few thousandths of an inch.

The results showed that the operations that must be most closely regulated are the casting of the electrotype metal and the final curving of the plates. It is hoped that the application of these results and principles will contribute to the production of the highest grade of printing by means of electrotypes.

The work will be described at greater length in the May number of the *Bureau of Standards Journal of Research.*

FREEZING AND THAWING TESTS OF SAND-LIME BRICK.

Absorption determinations and freezing and thawing tests were made on sand-lime brick primarily to determine the value of absorption requirements in specifications as an index of weather resistance. Little relation between amount of absorption and resistance to freezing and thawing was apparent. It was found, however, that a brick having both a fast rate of absorption in partial immersion and a high strength was likely to withstand freezing and thawing satisfactorily.

ENGLISH CHINA CLAY.

In order to investigate some of the characteristics of the colloids of a clay, the ignition loss, silica content, RO and R_2O_3 content of the colloidal fractions of 10 English china clays have been determined. The silica was determined by double dehydration and corrected for the amount carried down by the R_2O_3. The R_2O_3 was obtained by double precipitation. Calculation of the $SiO_2 : R_2O_3$ ratios from the chemical analyses of the colloids showed a variation of from 1.91 to 2.85. The

same ratios, obtained from the analyses of the original clays, varied from 1.96 to 2.13. There was no apparent relation between the ratios obtained from the clays and those from the extracted colloids. For example, the clay having the lowest $SiO_2 : R_2O_3$ ratio yielded the colloid which had the highest ratio. In most cases the ratio was higher in the colloid than in the original clay. Two clays were exceptions to this rule.

The RO content of the colloidal fractions of the clays varied from 1.60 to 9.17 per cent., being in nearly all cases, higher than for the original clays, which showed a variation of from 1.47 to 2.75 per cent. Here again there was no obvious relation between the clay and its colloidal extract. The same can be said of the ignition loss, which in some cases was higher for the colloid fraction and in others lower than for the original clay.

Insufficient data have been collected to warrant any conclusions at this time. It is hoped that a determination of the dialysable bases in the clays, and the percentage of colloids, by water adsorption of hydrogen-saturated samples of the clays and their colloids, will indicate more clearly the function of the colloids.

SPECIFIC GRAVITY AND POROSITY OF KAOLINS AFTER FIRING.

In connection with a study of the differences found in linear thermal expansion of kaolins obtained from some of the more important world sources it seemed advisable to determine among other properties the true specific gravity and porosity. The values obtained after firing these materials to six different temperatures are tabulated below. The pyrometric cone equivalent (softening point) of each of the five kaolins included in this work was 35.

North Carolina kaolin shows the smallest change in porosity over the range of temperatures used and English china clay the greatest. In general the specific gravity slightly increases with the increase of temperature to 1250° C., decreases up to 1400° C. and increases again at 1500° C. The greatest changes in this property due to increasing temperature of firing are indicated by the Georgia and Zettlitz kaolins.

Kaolin Identity.	True Specific Gravity and Porosity.	Temperature of Firing (° C.).					
		1150	1200	1250	1300	1400	1500
North Carolina	Sp. gr.....	2.709	2.711	2.732	2.696	2.706	2.707
	Por., per cent.....	46.45	45.78	43.50	41.18	34.60	31.80
Delaware.....	Sp. gr.....	2.712	2.724	2.719	2.705	2.675	2.689
	Por., per cent.....	39.47	37.18	32.10	24.02	6.79	1.50
Georgia.....	Sp. gr.....	2.748	2.787	2.801	2.815	2.781	2.793
	Por., per cent,....	39.0	33.32	32.3	30.18	9.10	2.57
Zettlitz.....	Sp. gr.....	2.748	2.755	2.762	2.733	2.695	2.749
	Por., per cent.....	37.17	34.42	30.7	22.12	1.74	.64
English.....	Sp. gr.....	2.714	2.723	2.725	2.734	2.702	2.700
	Por., per cent.....	41.15	37.00	28.40	22.72	10.04	.50

FUSION PROPERTIES OF TYPICAL COMMERCIAL GROUND COAT ENAMELS.

The present item concerns a continuation of an investigation referred to in Technical News Bulletin No. 164 (December, 1930) under the title, "Effect of Variations in Composition on Properties of Vitreous Enamels." A group of ground coat enamels, varying in flint-feldspar ratio and in sodium-boric oxide ratio over the moderate extremes of practical limits, has been subjected to various fusion tests, as follows: (*a*) miniature cone deformation tests, (*b*) "fusion block" flow tests, (*c*) slumping temperature tests, and (*d*) "button" tests. The method of making cone deformation tests is well known. The fusion block test consists in packing a cavity in the block with enamel powder and heating the whole on a definite schedule. The enamel flows down a steeply inclined plane, bearing calibration marks, and the time and temperature required for the stream to pass certain calibration marks are observed. The slumping temperature is taken as that temperature at which a specimen of enamel ceases to increase in height and begins to slump with increase in temperature, as indicated by interferometer measurements. The "button" test consists of subjecting cylinders of enamel powder to a standard heat treatment, and observing the height and diameter of the resulting "buttons."

The following table applies only to the cone deformation temperatures of one set of enamels, but is also fairly typical of the effect of these variations in composition upon the refractoriness of the enamels as indicated by all of the other above mentioned tests, also.

Enamel.	Composition.[1]				Cone deformation temperatures.	
	Feldspar, Parts	Flint, Parts	Sodium Oxide, Parts	Boric Oxide, Parts	° C.	° F.
a	35	25	17	13	645	1193
b	35	25	14	16	670	1238
c	35	25	11	19	690	1274
d	30	30	17	13	648	1198
e	30	30	14	16	676	1249
f	30	30	11	19	698	1289
g	25	35	17	13	659	1218
h	25	35	14	16	688	1270
i	25	35	11	19	707	1304

[1] Constant portion of batches not given.

From this table and other similar data which cannot be given here it is apparent that variations in the sodium-boric oxide ratio had considerably more effect upon the refractoriness than was produced by variations in the flint-feldspar ratio. Thus the change from (*a*) to (*b*), representing a replacement of three parts of sodium oxide by boric oxide, caused an elevation in cone deformation temperature of 25° C. (45° F.), while the change from (*a*) to (*g*), representing a replacement of ten parts of feldspar by flint, caused an elevation of only 14° C. (25° F.). In the first case the numerical value of the ratio of the two constituents involved was reduced by about one-third, while in the second case it was reduced by approximately one-half.

THE FRANKLIN INSTITUTE.

MONTHLY MEETING—MEDAL DAY—MAY 20, 1931.

The stated monthly meeting of the Institute was called to order at three-thirty P.M. by the President of the Institute, Mr. Nathan Hayward.

The Chairman stated that the minutes of the April meeting had been printed in full in the May number of the JOURNAL of the Institute and that, if there were no objections, the minutes would stand approved as printed. No objection was uttered and the minutes were declared approved.

The Chairman then stated that the next business of the meeting was the presentation of medals which had been recommended by the Committee on Science and the Arts and voted by the Board of Managers throughout the past year. Certificates of Honorary Membership were also presented.

The order of awards proceeded as follows:

PROGRAMME.

	Sponsors
Presentation of Longstreth Medal to	
CHARLES G. GARRARD, M.E. Thorn, England	Mr. J. A. Vogleson
Presentation of Wetherill Medals to	
THOMAS TARVIN GRAY (deceased), President Gray Industrial Laboratories Newark, New Jersey Represented by Mr. A. McD. Gray, brother	Dr. T. K. Cleveland
ARTHUR J. MASON Homewood, Illinois	Mr. S. Shoemaker
HENRY M. SUTTON, EDWIN G. STEELE AND WALTER L. STEELE Sutton, Steele and Steele, Inc. Dallas, Texas	Mr. O. B. Evans
EDWARD C. WENTE, PH.D. Bell Telephone Laboratories, Inc. New York City	Mr. W. G. Ellis
Presentation of Levy Medal to	
J. STUART FOSTER, PH.D., F.R.S.C. Assistant Professor of Physics McGill University Montreal, Canada	Dr. F. Palmer, Jr.
Presentation of Henderson Medal to	
ARTHUR NEWELL TALBOT, SC.D., D.ENG. Professor of Engineering, Emeritus University of Illinois Urbana, Illinois	Mr. B. Franklin

Presentation of Clark Medal to
DANIEL J. YOUNG — Mr. T. F. Clark
Consulting Engineer
Tacoma, Washington

Presentation of Potts Medal to
BENNO STRAUSS, PH.D. — Mr. C. Sellers, 3rd
Essen, Germany
Represented by Dr. O. C. Kiep
German Consulate General
New York City

Presentation of Cresson Medals to
CLINTON J. DAVISSON, PH.D., AND LESTER H. GERMER, PH.D. — Dr. W. O. Sawtelle
Bell Telephone Laboratories, Inc.
New York City

KOTARO HONDA, Professor — Mr. H. B. Allen
Director, Research Institute for Iron, Steel and Other Metals
Tohoku Imperial University
Sendai, Japan
Represented by the Honorable K. Midzusawa
First Secretary of the Japanese Embassy
Washington, D. C.

THEODORE LYMAN, PH.D. (in absentia) — Dr. W. R. Wright
Director Emeritus, Jefferson Physical Laboratory
Harvard University
Cambridge, Massachusetts

Presentation of the Franklin Medal and Certificate of Honorary Membership to
WILLIS RODNEY WHITNEY, PH.D., SC.D., CH.D. — Dr. James Barnes
Vice-President in Charge of Research
General Electric Company
Schenectady, New York

Presentation of the Franklin Medal and Certificate of Honorary Membership to
SIR JAMES HOPWOOD JEANS, KT., F.R.S., LL.D., D.Sc. — Dr. Barnes
Dorking, England

After the presentation exercises, the following papers were read:

"Research: Theory and Practice," by Dr. Willis R. Whitney.

"The Origin of the Solar System," by Sir James Hopwood Jeans.

The President then declared the meeting adjourned, at four-forty-five P.M.

HOWARD MCCLENAHAN,
Secretary.

(An extended account of the proceedings of this Medal Day meeting will appear in an early issue of the JOURNAL.)

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, May 13, 1931.)

HALL OF THE COMMITTEE,
PHILADELPHIA, MAY 13, 1931.

MR. LIONEL F. LEVY *in the Chair.*

The following report was presented for final action:

No. 2902: Televox.

The following reports were presented for first reading:

No. 2838: Paulin Altimeter.
No. 2927: Electric Flow Meter.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, May 20, 1931.)

RESIDENT.

MR. DANIEL B. CURLL, JR., Industrial Chemistry, Philadelphia Quartz Company, 121 South Third Street, Philadelphia, Pa. For mailing: Wayne, Pa.

MR. HARRY C. KAHN, Merchant, N.W. corner Eleventh and Filbert Streets, Philadelphia, Pa.

MR. L. P. SHARPLES, Engineer, Vice-President, Sharples Specialty Company, Twenty-third and Westmoreland, Philadelphia, Pa.

CHANGES OF ADDRESS.

DR. ROBERT J. ANDERSON, 1272 West 112 Street, N.W., Cleveland, Ohio.

MR. S. BUNKER CAPP, c/o The Librarian, N.W. corner Fifteenth and Cherry Streets, Philadelphia, Pa.

MR. JOHN J. CATON, 16212 Fairfield Avenue, Detroit, Michigan.

MR. R. F. GELLER, 306 West Thornapple Street, Chevy Chase, Maryland.

MR. JOHN J. GIBSON, Vice-President, Westinghouse Electric Supply Company, 150 Varick Street, New York City.

MR. A. C. HOWARD, Room 1008, Hazen Building, 122 Greenwich Street, New York City.

MR. J. W. HOWELL, 211 Ballatine Parkway, Newark, N. J.

MR. W. J. JEFFRIES, 812 Serrill Avenue, Yeadon, Delaware County, Pa.

MR. J. J. KENNEDY, 26 Court Street, Brooklyn, N. Y.

DR. ARTHUR R. KNIPP, Lingnan University, Canton, China.

MR. H. H. KNOX, 495 Belmore Way, Pasadena, California.

MR. J. H. MANNING, c/o Stone and Webster Engineering Corporation, 90 Broad Street, New York City.

MR. ALBERT W. MORRIS, 54 Burkingham Street, Springfield, Mass.

MR. WILLIS A. NAUDAIN, P. O. Box 846, Wilmington, Delaware.

MR. GEORGE A. ORROK, 21 East Fortieth Street, New York City.
MR. HAVILAND H. PLATT, Osterville, Mass.
MR. C. E. POSTLETHWAITE, Assistant Vice-President, c/o Pressed Steel Car Company, 80 Broad Street, New York City.
MR. VICTOR H. SEVERY, 1348 Venice Boulevard, Pico Station, Los Angeles, California.
MR. GEORGE N. SIEGER, c/o P. R. Mallory and Company, Inc., 3029 East Washington Street, Indianapolis, Indiana.
MR. PAUL E. TODD, 1127 Sixth Street, S.E., Minneapolis, Minn.

NECROLOGY.

Mr. Charles Day, Philadelphia.
Dr. Francis X. Dercum, Philadelphia.
Dr. R. B. Moore, Lafayette, Indiana.
Dr. John E. Teeple, New York City.

LIBRARY NOTES.

RECENT ADDITIONS.

American Institute of Electrical Engineers. Transactions. Volume 50, Number 1, March, 1931.
American Pharmaceutical Association. Year Book 1927 and 1928. Volumes 16 and 17. 1929.
ANDERSON, ROBERT J. Secondary Aluminum. 1931.
Autolykos. Rotierende Kugel und Aufgang und Untergang der Gestirne. Theodosios von Tripolis. Sphaerik. Ostwald's Klassiker der exakten Wissenschaften Nr. 232. 1931.
BAKER, JOHN W. Natural Terpenes, 1930.
BEILBY, SIR GEORGE. Aggregation and Flow of Solids. 1921.
BERNEWITZ, M. W. VON. Handbook for Prospectors. Second edition. 1931.
BERNTHSEN, A. A Textbook of Organic Chemistry. New Edition, revised to date by J. J. Sudborough. 1931.
BRIGGS, DENNIS BROOK. Practical Glass Manipulation. 1926.
Chemical Society [of London]. Annual Reports on the Progress of Chemistry for 1930. Volume 27, 1931.
DEFELD, RAYMOND. A Practical Treatise on Single and Multi-Stage Centrifugal Pumps. Translated by C. W. Olliver. 1930.
FAJANS, K., AND J. WÜST. A Textbook of Practical Physical Chemistry. Translated from the German by Bryan Topley. No date.
GARDNER, W. Fertilisers and Soil Improvers. 1927.
HACKLEMAN, CHARLES W. Commercial Engraving and Printing. 1924.
ISRAEL, HANS, ERICH RUCKHABER, AND RUDOLF WEINMANN, Editors. Hundert Autoren gegen Einstein. 1931.
JEANS, SIR JAMES. Astronomy and Cosmogony. 1929.
JEANS, SIR JAMES. The Stars in Their Courses. 1931.
LOOMIS, FREDERIC BREWSTER. Field Book of Common Rocks and Minerals. 1923.

McILWAIN, KNOX, AND J. G. BRAINERD. High Frequency Alternating Currents. 1931.

MONTESSUS DE BALLORE, R. DE. Probabilités et Statistiques. 1931.

MOYER, JAMES A., AND JOHN F. WOSTREL. The Radio Handbook. First edition. 1931.

NEBLETTE, C. B. Photography: Its Principles and Practice. Second edition. 1931.

OMWAKE, JOHN. The Conestoga Six-Horse Bell Teams of Eastern Pennsylvania. 1930.

Organic Syntheses: an Annual Publication of Satisfactory Methods for the Preparation of Chemicals. Volumes 6-10. Five volumes. 1926–1930.

REYNER, J. H. Testing Radio Sets. 1930.

Society of Chemical Industry. Annual Reports on the Progress of Applied Chemistry. Volume 15, 1930.

STORY, JOHN P. Elements of Elastic Strength of Guns. 1894.

SWAIN, GEORGE FILLMORE. Structural Engineering: Volume I, Strength of Materials; Volume II, Fundamental Properties of Materials; Volume III, Stresses, Graphical Statics and Masonry. Three volumes. 1924–1927.

United States Patent Office. Index of Trade-Marks 1930, 1931.

VOGEL, HANS, AND ALFRED GEORG. Tabellen der Zucker und ihrer Derivate. 1931.

WEINSTEIN, MICHAEL. Precious and Semi-Precious Stones. Second edition. 1930.

Wien-Harms Handbuch der Experimentalphysik. Band 25, 2 Teil. 1931.

BOOK REVIEWS.

L'EVOLUTION ET LE DÉVELOPPEMENT DES PRINCIPALES INDUSTRIES DEPUIS CINQUANTE ANS (1880–1930). Numero speciale publié a l'occasion du Cinquantenaire du Genie Civil—236 pages quarto, illustrations, paper. Paris, Bureau du Genie Civil. Price 25 frs.

The fiftieth anniversary of this widely known journal of industrial arts is fittingly celebrated by a collection of monographs on the evolution and progress of typical industries during that period. There are forty-two papers, all-told, including a short historical account of the journal during its fifty years of existence. The authors are notable specialists in French science or industry: twelve are members of the *Institut*, seven former presidents of the society of civil engineers and the greater part of the others professors in the foremost engineering schools of Paris. The collection is of rare interest, well illustrated and representative.

L. E. P.

A TEXTBOOK OF PRACTICAL PHYSICAL CHEMISTRY, by F. Fajans, Professor of Physical Chemistry in the University of Munich and J. Wüst. Translated from the German by Bryan Topley with a preface by F. G. Donnan, LL.D., F.R.S. XV–233 pages, diagrams, 8vo, New York, E. P. Dutton & Company, Inc. Price, $4.95.

No doubt many a teacher of physical chemistry will feel that this book is "Just what he has been looking for." With aid from some of their colleagues the

authors have evolved a text on practical physical chemistry which for its size, would be difficult to surpass in its clarity and detail. In addition to the excellent directions on how to carry out these physical chemistry measurements, each unit of experimental procedure is prefaced by an appropriate theoretical exposition which will give the student a better insight into the laws characterizing the physical and chemical properties of substances as well as teach him the significance of his results and enable a correct evaluation of the data.

The book is quite up to date and contains practically all the well established methods universally employed by chemists in their physical-chemistry researches. Among those procedures of more recent development we may list: (1) Coagulation of a Sol by Electrolytes of Different Valencies; (2) The Transformation of Radio-Elements; (3) Ultra-Violet Spectrography; (4) Preparation of Substances by Electrochemical Means.

T. K. CLEVELAND.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 374, The Automotive Ignition Coil, by T. H. Darnell, 28 pages, illustrations, quarto. Washington, Government Printing Office, 1931. Price twenty-five cents.

This paper which was submitted by the Bureau of Standards for publication gives the results of an extensive series of measurements on the secondary voltage induced in an ignition coil of typical construction under a variety of operating conditions. These results show that the theoretical predictions hitherto made as to the behavior of this type of apparatus are in satisfactory agreement with the observed facts. The large mass of data obtained is here published both for the use of other investigators who may wish to compare them with other theoretical predictions and for the use of automotive engineers who will here find definite experimental results showing the effect of secondary capacity and resistance on the crest voltage produced by ignition apparatus.

Report No. 379. Rolling Moments due to Rolling and Yaw for Four Wing Models in Rotation, by Montgomery Knight and Carl J. Wenzinger, 27 pages, illustrations, quarto. Washington, Government Printing Office, 1931. Price fifteen cents.

This report presents the results of a series of auto-rotation and torque tests on four different rotating wing systems at various rates of roll and at several angles of yaw. The investigation covered an angle-of-attack range up to 90° and angles of yaw of 0°, 5°, 10°, and 20°. The tests were made in the 5-foot, closed-throat atmospheric wind tunnel of the National Advisory Committee for Aeronautics. The object of the tests was primarily to determine the effects of various angles of yaw on the rolling moments of the rotating wings up to large angles of attack.

It was found that at angles of attack above that of maximum lift the rolling moments on the wings due to yaw (or side slip) from 5° to 20° were roughly of the same magnitude as those due to rolling. There was a wide variation in magnitude of the rolling moment due to yaw angle with both angle of attack and with pb/2V. The rates and ranges of stable autorotation for the monoplane models were considerably increased by yaw, whereas for an unstaggered biplane

they were little affected. The immediate cause of the rolling moment due to yaw is apparently the building up of large loads on the forward wing tip and the reduction of loads on the rearward wing tip.

Report No. 384. The Comparative Performance of Superchargers, by Oscar W. Schey, 15 pages, illustrations, quarto. Washington, Government Printing office, 1931. Price five cents.

This report presents a comparison of superchargers on the basis of the power required to compress the air at a definite rate, and on the basis of the net engine power developed at altitudes from 0 to 40,000 feet. The investigation, which was conducted at the Langley Memorial Aeronautical Laboratory, included geared centrifugal, turbine-driven centrifugal, Roots, and vane-type superchargers. It also includes a brief discussion of the mechanical limitations of each supercharger and explains how the method of control affects the power requirements.

The results of this investigation show that for critical altitudes below 20,000 feet there is a maximum difference of about 6 per cent between the amounts of net engine power developed by the various types of superchargers when ideal methods of control are employed, but for critical altitudes above 20,000 feet an engine develops considerably more power when equipped with a turbocentrifugal supercharger than with any other type. The Roots type gives the lowest net engine power of all at high critical altitudes, because it has the least efficient type of compression.

The throttling method of control used on the geared-centrifugal type of supercharger is very unsatisfactory at low altitudes from a net engine power standpoint when compared with the method used on the Roots or turbocentrifugal.

R.

FLOW AND MEASUREMENT OF AIR AND GASES. By Alec B. Eason, M.A., of the Engineer-in-Chief's Office, G.P.O., Assoc. M. I. C. E., M. I. E. E. M. I. Post Office Engineers. Second edition, thoroughly revised. xii–254 pages, 8vo, cloth, illustrations. Philadelphia, J. B. Lippincott Company, 1930.

The analysis of the motion of fluids has always proved a most elusive study and the assumption of stream-line flow has governed the purely theoretic side of the subject. Since a formula so derived is only representative within a limited range of conditions, an immense amount of experimental work has been done in hydraulic projects, and more latterly on air and gas transmission systems, to determine coefficients which will give the theoretical formula applicable value. The transmission of air and gases being a development of less maturity than the flow of water, in gathering between the covers of a single volume a highly documented synopsis and critical review of a representative collection of investigations of air- and gas-flow, the author has provided a source of information from original sources which should be invaluable alike to the practicing engineer and the advanced student. The subject is discussed under three main divisions: (I) the friction of gases and the coefficient of friction in pipes; (II) the question of suitable meters for gas and air; (III) the working of pneumatic tubes. The specific problems investigated comprise pneumatic tubes, compressed-air systems, gas-lighting systems and ventilating systems.

In a digest of this kind, it is scarcely to be expected that any new or radical departure will be evolved in the design of air and gas lines. The author, however, does recommend certain values of the friction coefficient in steam and air lines for approximate computation. The Unwin formula, in which the coefficient of friction varies with the diameter of pipe, he regards as reasonably satisfactory. An inset chart of this formula is provided to facilitate its use. On the loss of pressure at fittings and the determination of the equivalent length of pipe, citations on current practice are made at considerable length, but no general conclusions are drawn. Pneumatic tube problems, theories of air flow in pipes, transit time of carriers, and intermittent flow of air in pipes are of particular interest in the planning of the cash carrying systems widely used in stores. The successful use of a system (Batcheller) of that kind in the post office service of this city some years ago will be recalled. The tube was of smooth bored cast iron 6⅛ inches in diameter and about half a mile long. It was abandoned with the adoption of the automobile truck. A much larger installation was in use by the New York City post office at about the same time.

Meters for gas and air are very fully considered, a wide variety being described with particular analytical treatment of the venturi and orifice types; anemometers are also given attention. Measurement of air by pitot tubes, and electric velocity meters and hot-wire anemometers each have a chapter. Very little work on air-flow is cited prior to 1900 in the bibliography. It is interesting to record that the French inventor Eug. Bourdon made some notable experiments in the measurement of air-currents by the use of venturi tubes which were published in *Comptes Rendus* for 30 Jan. 1882. These experiments, it appears, were the inspiration and forerunner of the famous work of Clements Herschel in the development of the venturi meter. Bourdon used a small venturi tube placed within a much larger one with its entrance orifice at the throat of the larger one so magnifying the effect. No illustrations or diagrams of actual apparatus are shown but an ample collection of graphs is provided with the analytical matter. An extensive bibliography is included which is arranged separately under "books" and "periodicals."

L. E. P.

MAN AND THE STARS. By Harlan True Stetson, Director of the Perkins Observatory, Ohio Wesleyan University. xiii–221 pages, with 30 half-tone plates and 25 text illustrations, 8vo. New York, Whittlesey House, 1930. Price $2.50.

Formerly a teacher of astronomy at Harvard, with many years experience to his credit, and now the director of an observatory which pays special attention to bringing astronomy before the public, Dr. Stetson is particularly well qualified to answer many of the questions that the laymen puts to the astronomer. In addition, his experience in research gives his writings a great degree of authority. However, "Man and the Stars" is not a text-book, nor even a general popular guide to the heavens, as the author is careful to point out in his preface. Rather is it, to quote his words, an effort "to present in readable form some of the outstanding events in man's discovery of a universe of unending change, and to trace the influence of these events upon man's reaction to his environment."

The work comprises eighteen chapters, divided into four parts. In parts I

and II, entitled respectively "Looking Skyward" and "Changing Concepts," he relates the historical steps that have led to the present ideas of the universe. The ideas of the ancient Greeks, the work of Copernicus in calling attention anew to the heliocentric conception of Aristarchus, the explorations of the sky by Tycho Brahe and Kepler, the contributions of Galileo despite the opposition of the church, the triumphs of Newton and the new concepts introduced by Herschel —all these are covered in an interesting and concise fashion.

In part III, "The Changing Universe," he summarizes some of the achievements of modern astronomy, such as the knowledge of the physics of the stars that we have gained from studies of their spectra; stellar evolution, and the probable source of their energy; methods of measuring stellar distances by such tools as the period-luminosity law in connection with the Cepheid variables; and the place of our Galaxy among the millions of other galaxies in the universe. Two chapters in this part deal with the Sun, and a rather detailed description is given of the author's own researches in correlating solar variation and radio reception. The last chapter of this section deals with the "cosmic clouds" of dark matter that appear, to quote Herschel's words, as "a hole in the sky."

Part IV, "Man Wonders," has been included, the author states, "to answer questions which I have often been asked in informal gatherings after lectures." This consists of three chapters, "Is There Life on Other Planets?" "Has Life any Cosmic Significance?" and "Has Science Displaced Religion?"

To the first of these questions, he answers: "It seems almost unthinkable that in a universe of several billion suns there should not evolve here and there, even though rarely, planetary systems not very different from that surrounding our own sun. In such systems around some distant stars there may be now some planet far more like the earth than is the planet Mars. On the grounds of similarity and unity of matter there is, perhaps, the strongest argument for the universality of life."

That life is "a common denominator to all creation," is the suggestion he makes in the second chapter of this part. "Are we ourselves perhaps a limited expression of an all-pervading consciousness? May some spark of such consciousness exist potentially with the smallest units of matter?" he asks, and answers "Such a conception is not at variance with the thought of many creative minds in the realms of philosophy, of religion and of science." Finally, in answer to his third question, he says "It is inevitable that the study of astronomy should make impossible the retention of certain theological conceptions of yesterday." But, he continues, "I hesitate to think that any vital religion shall ever ultimately suffer through the patient and persistent searchings of science in the acquisition of truth."

Physically, the book does credit to its publishers. In every respect it can be recommended to the general reader, but not as a book in which he will find summarized the whole field of astronomy. There are plenty of good books filling that need, several of which have been reviewed in this JOURNAL in recent months. To the layman, who reads it and reflects upon its message, should come a broadening of his horizon and a better insight into some of the problems confronting the scientist.

JAMES STOKLEY.

STANDARD FOUR FIGURE MATHEMATICAL TABLES. By L. M. Milne-Thomson, M.A., Assistant Professor of Mathematics in the Royal Naval College; and L. J. Comrie, M.A., Ph.D., Superintendent, His Majesty's Nautical Almanac Office. Edition A, with positive characteristics in the logarithms. xvi–245 pages, 4to. London, Macmillan and Co., 1931. Price $4.50.

FOUR FIGURE TABLES OF THE NATURAL AND TRIGONOMETRICAL FUNCTIONS, with the argument in time. By L. J. Comrie, M.A., Ph.D., Superintendent, His Majesty's Nautical Almanac Office. 32 pages, 4to. London, published by the author, 1931. Price $1.00.

So numerous are the excellent tables of logarithms and trigonometric functions now on the market that it might almost seem a work of supererogation to prepare a new one. Instead, however, the present volume admirably fills a place that has long been vacant in the library of aids to the computer. Five, six, seven and even ten place tables are common, but, so far as the reviewer is aware, Desvallées' excellent little book, published at Paris in 1919, contains the only satisfactory four place tables that have been available up to now. Of course, for much scientific computation, a greater degree of accuracy is essential, but to use a six or seven place table where only four are needed is a decided waste of time and effort, which can now be saved.

The appearance of Dr. Comrie's name on the title page of the present work is a guarantee of the care that has been taken in the preparation of the tables. As superintendent of the British Nautical Almanac Office, he is a recognized authority in the field of mathematical tables, and is particularly known for his application of various forms of computing machines to lessen the drudgery and increase the accuracy of their preparation. Many of the tables in this volume were calculated with such aids.

Nineteen main tables are given, including logarithms, antilogarithms, addition and subtraction logarithms, roots, powers and reciprocals, natural and logarithmic functions, with argument in degrees and in radians, inverse functions and natural logarithms, Gudermannians, gamma functions, coefficients of the second difference and conversion between degrees and radians. Following the tables proper are given lists of derivatives, integrals, series, formulæ, differential equations, constants and proportional parts. For greater convenience in use, the table of proportional parts is also printed separately on a card given with each book, so that it may be kept at hand when using any page.

A word should be said about the two editions of the work. In America we are used to expressing logarithms of numbers less than unity with positive characteristics by increasing them by ten. This is common practice among scientists throughout the world, but in the English schools, with characteristic British conservatism, the use of negative characteristics is still taught. To cater to both groups, the publishers have issued two editions. Edition A follows the American practice, and, for example, the logarithm of 0.1734 is printed as 9.2390, while Edition B gives it as $\bar{1}$.2390. The former, of course, is much more convenient, and it is Edition A that most readers of this JOURNAL would want.

To the astronomer, there is one rather important omission in these tables, namely, natural and logarithmic trigonometrical functions with the argument in time. An astronomer himself, Dr. Comrie has felt this omission, and has

remedied it by the private publication of such tables as a separate pamphlet. This is in the same format as the larger work, in which it can easily be inserted. It can be obtained from the author at H. M. Nautical Almanac Office, Royal Naval College, London, S. E. 10.

JAMES STOKLEY.

ALTERNATING CURRENT BRIDGE METHODS FOR THE MEASUREMENT OF INDUCTANCE, CAPACITANCE AND EFFECTIVE RESISTANCE AT LOW AND TELEPHONIC FREQUENCIES. A theoretical and practical handbook for the use of advanced students, by B. Hague, D.Sc. (Lond.), lecturer in electrical engineering in the University of Glasgow, second edition, revised and enlarged. xvi–391 pages, diagrams, 8vo. New York, Isaac Pitman & Sons. Price $4.50.

This second edition, the first of which was issued in 1923, has been enlarged and quite thoroughly revised. Without a doubt it will prove to be an immense aid to the technician occupied with the testing of various parts of electrical apparatus as well as serving the research student in the capacity of a very complete text and reference book.

The first chapter deals with fundamental principles. Herein is given the history and development of the bridge principle. In addition, the dimensions and units for resistance, capacitance and inductance are defined and interrelated by use of the fundamental electrical units.

Chapter II covering the symbolic theory of alternating currents and its application to bridge networks begins with a discussion on vectors and then proceeds to develop the alternating current equations which are specific for the various types of bridge formations.

In Chapter III the author has gone to great lengths in his descriptions of apparatus. This is especially evident in his discussion on standards of resistance, self and mutual inductance, capacitance and sources of alternating current. Detectors or galvanometers also receive their full share of recognition.

In Chapter IV on the classification of bridge networks the author has thoroughly covered the numerous types of bridges representing the various combinations of resistance, inductance and capacitance. Such systems here described will and do find application in telephonic research, testing of dielectric losses in cables and insulators, losses in synchronous condensers and large oil switches as well as the measurement of power factors and a.c. frequencies.

Chapter V should prove especially helpful since it deals with the choice of a bridge method for any particular job and the precautions to be observed when using it.

The book has been limited to considering the types of bridges which may be used within the range of frequency lying between a few cycles per second and the highest acoustical values encountered in telephonic research, a few thousand cycles per second. The author has carefully tried to furnish full references to any papers which have served as original sources for the text.

T. K. CLEVELAND.

PUBLICATIONS RECEIVED.

A Monograph of Viscometry, by Guy Barr, B.A., D.Sc. 318 pages, illustrations, 8vo. New York, Oxford University Press, 1931. Price $12.00.

Essentials of Quantitative Chemical Analysis, A Laboratory Manual for Colleges, by Wilfred W. Scott, Sc.D. 219 pages, illustrations, 8vo. Easton, The Chemical Publishing Company, 1931. Price $2.75.

The Metallic State, Electrical Properties and Theories, by W. Hume-Rothery, M.A., Ph.D. 371 pages, illustrations, tables, 8vo. New York, Oxford University Press, 1931. Price $9.00.

Institut de Mecanique des Fluides de l'Universite de Paris, Propagation d'Une Onde Sonore dans l'Atmosphere et Theorie des Zones de Silence, par Henri Galbrun. 352 pages, illustrations, 8vo. Paris, Gauthier-Villars et Cie, 1931. Price 70 francs.

The Theory and Practice of Radio Frequency Measurements, a handbook for the laboratory and a text-book for advanced students, by E. B. Moullin, M.A. A.M.I.E.E., M.I.Rad.Eng., second edition. 487 pages, illustrations, 8vo. London, Charles Griffin & Co., Ltd.; Philadelphia, J. B. Lippincott Company, 1931. Price $12.50.

Mathematical and Geometrical Demonstrations, by Carl Theodore Heisel, Extraordinary and Significant Discoveries of a Lacking Link, by Carl Theodore Faber in the Demonstration of the World Renowned Pythagorean Problem. 128 pages, illustrations quarto. Cleveland Author, 1931.

Union Internationale de Chimie, Comptes Rendus de la Dixieme Conference, 1930. 71 pages, quarto. Paris, Union, n.d.

National Advisory Committee for Aeronautics. Technical Notes, No. 370, Strength Tests on Paper Cylinders in Compression, Bending, and Shear, by Richard V. Rhode and Eugene E. Lundquist, Langley Memorial Aeronautical Laboratory, 14 pages, tables, plates, quarto. Washington, Committee, 1931. No. 371, Experiments with an Airfoil Model on which the Boundary Layer is Controlled without the Use of Supplementary Equipment, by I. H. Abbott, Langley Memorial Aeronautical Laboratory, 6 pages, plates, quarto. Washington, Committee 1931. No. 372, Development of an Impinging-Jet Fuel-Injection Valve Nozzle, by J. A. Spanogle and G. T. Hemmeter, Langley Memorial Aeronautical Laboratory, 9 pages, plates, quarto. Washington, Committee 1931. No. 373, Investigation of the Discharge Rate of a Fuel-Injection System, by Harold C. Gerrish and Fred Voss, Langley Memorial Aeronautical Laboratory, 11 pages, tables, illustrations, quarto. Washington, Committee, 1931. No. 374, Preliminary Study of Applied Load Factors in Bumpy Air, by Richard V. Rhode and Eugene E. Lundquist, Langley Memorial Aeronautical Laboratory, 30 pages, tables, plates, quarto. Washington, Committee, 1931. No. 375, Moments of Inertia of Several Airplanes, by Marvel P. Miller and Hartley A. Soule, Langley Memorial Aeronautical Laboratory, 6 pages, tables, illustrations. Washington, Committee, 1931.

The Story of Soap, unpaged, illustrations, square 12mo. Cincinnati, Procter & Gamble, 1931.

A List of Alloys with Physical Properties of Typical Alloys, by William Campbell, 65 pages, 8vo. Philadelphia, American Society for Testing Materials, n.d.

La conservation de l'Energie et les mouvements des corps, par C. Boeresco, 15 pages, illustrations, 8vo. Bucarest, Copuzeanu, 1931.

U. S. Bureau of Mines Technical Paper 496, Accuracy of Manometry of Explosions, by C. M. Bouton, H. K. Griffin and P. L. Golden, 52 pages, plates, diagrams, 8vo. Washington, Government Printing Office, 1931. Price fifteen cents. *Technical Paper 497, Electromagnetic Absorption by Rocks with some Experimental Observations Taken at the Mammoth Cave of Kentucky*, by J. Wallace Joyce, 28 pages, plates, tables, diagrams, 8vo. Washington, Government Printing Office, 1931. Price ten cents. *Gold, Silver, Copper, and Lead in South Dakota and Wyoming in 1929*, Mine Report, by Chas. W. Henderson, 273 pages, tables, 8vo. Washington, Government Printing Office. Price five cents.

Mellon Institute of Industrial Research, Bibliographic Series Fourth Supplement to Bulletin No. 2, A List of the Books, Bulletins, Journal Contributions, and Patents by Members of Mellon Institute of Industrial Research during the Calendar Year 1930, by Lois Heaton Pugsley, 10 pages, 8vo. Pittsburgh, Mellon Institute, 1931. The Activities of Mellon Institute during 1930–31, 14 pages, 8vo. Reprinted from Industrial and Engineering Chemistry, 1931. Pittsburgh, Mellon Institute, 1931.

U. S. Department of Labor, Prices Wholesale and Retail, March 1931, 23 pages, 8vo. Washington, Government Printing Office, 1931.

U. S. Public Health Service, Detailed Instructions for the Performance of the Dissolved Oxygen and Biochemical Oxygen Demand Tests, by Emery J. Theriault. 33 pages, 8vo. Washington, Government Printing Office, 1931. Price ten cents.

CURRENT TOPICS.

Theories of Terrestrial Magnetism. F. E. SMITH. (*Nature*, Sept. 13, 1930.) Within the last half-century there has developed so great a confidence in the ability of science to solve all problems proposed to it, whether of a technical or of a theoretical character, that it is wholesome and conducive to a humbler attitude of mind to have attention directed to one of the hitherto unsolved enigmas of physics. This was done by Dr. Smith in his presidential address before the Section of Mathematics and Physical Sciences at the recent meeting of the British Association for the Advancement of Science held at Bristol.

Gauss showed that the chief cause of the earth's magnetic field lies within the earth and Schuster demonstrated that the origin of the daily variations is situated above its surface. The permanent magnetic field of the earth travels westward about the globe at the rate of a few seconds of longitude per day and in some centuries should complete a circuit in a direction opposite to that of the earth's rotation. This means, in other terms, that the axis of the earth's magnetism rotates around the axis of the earth. If there is above the earth a region capable of conducting electricity—and the phenomena of radio transmission indicates the existence of this property in the Kennelly-Heaviside layer—there is a magnetic field rotating within a closed conductor. In this currents must be induced. Between such currents in the conducting region and the rotating field of the earth a mechanical reaction results that tends to oppose the motion of the field, slowing down its rotation and finally making the axis of terrestrial magnetism to coincide with the axis of the earth. Too little is known about the uniformity and motion of the outer conducting region to permit more than broad generalizations to be sketched as to secular variations in terrestrial magnetism. A reason is provided for changes in the rotation of the magnetic field of the earth but not for the rotation itself.

The permanent magnetic field of the earth may be ascribed to its having a magnetic core. Next in simplicity is the attribution of the field to the effect of currents flowing in the earth. This theory must explain why the currents flow. Once set in motion such currents would continue to flow for a long time by reason of self-induction. Is there, however, any way of accounting for a permanent electromotive force to keep the currents flowing? In 1919 Larmor

called attention to an internal circulation of the material of the sun, indicated by certain surface phenomena. In continuation of this suggestion made for the sun Ross Gunn has proposed the theory that the terrestrial magnetic field is due to currents set up in the depths of the earth, where he assumes a temperature of 10,000°. Here ions would be plentiful and conductivity great. "It is considered that the primary current system of the earth results from the motions imposed upon ions having a mean free path of the order 10^{-7} cm., the motion being imposed by the internal gravitational electric field at right angles to the magnetic field. The currents produced augment the original field in a regenerative manner."

When it is sought to account for the earth's magnetic field by its rotation while having an electric charge either on its surface or distributed throughout its mass, insuperable difficulties are encountered. A generation ago Schuster raised the question whether every large body in rotation is not a magnet, apart from its possession of an electric charge. "The observed similarities between the magnetic fields of the earth and the sun, especially as the physical conditions are so different, naturally lend support to the theory that the magnetisation is brought about by rotation, and the fact that the axes of magnetisation and rotation do not coincide, while disturbing, may possibly be explained by reasonable assumptions." A slight magnetic effect has been obtained in the laboratory by rotating a body but its magnitude was too small to account for the magnetism of the rotating earth. Barnett was the first to show by experiment that magnetism is produced in iron by rotating it. The effect depends on gyroscopic action. It cannot serve to explain the magnetism of the earth because of its extreme smallness. On account of the difficulty of explaining terrestrial magnetism by the rotation of an electrically charged body or by the gyromagnetic effect recourse has been had to modifications of laws governing electrical actions. Sir J. J. Thomson proposed one such change. Swann suggested another that was open to an experimental verification. In collaboration with Longacre he rotated a copper sphere 10 cm. in diameter at 200 revolutions per sec., but the magnetic results obtained were not in accord with those required by theory.

It may be that a part of the terrestrial field is due to vertical electric earth-air currents. The evidence for the existence of such currents is conflicting. Rücker failed to find any evidence at all for areas in Great Britain, while Dyson and Furner concluded that the slight evidence they found was insufficient to make their existence certain. On the other hand Bauer in the United States has in every one of his many calculations discovered proof of their occurrence.

There are three theories to account for daily variations of the earth's magnetic field. One, the dynamo theory, depends on the production of electric currents in conducting masses of the upper air that move across the lines of force of the terrestrial field. In the diamagnetic layer theory, due to Gunn, the hemispherical conducting cap lying over that half of the earth facing the sun is held to be equivalent to a diamagnetic layer, which affects the magnetic field observable at the surface of the earth. Chapman's drift theory claims that in the upper conducting layers of air there is a drift of ions and electrons in a direction perpendicular to the lines of force and the gravitational field. Too little is known of conditions in the upper air to decide which theory comes nearest to rendering a satisfactory account of the daily variations.

An examination of magnetic records shows that there is a connection between variations of terrestrial magnetism and both the sun's period of rotation and the sunspot period. Magnetic storms have evoked many theories in explanation of them. One theory attributes them to the magnetic effect of a stream of charged particles emitted by the sun and equivalent to an electric current.

It will have been noticed that theories abound in the field of terrestrial magnetism but that the solid ground of demonstrated experimental explanation is lacking. G. F. S.

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